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# A Wearer-Centred Framework to Design for Wearability in Animal Biotelemetry

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This dissertation is submitted for the degree of  
Doctor of Philosophy

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## Abstract

In a technological era, monitoring animals for scientific, husbandry, or caring reasons is often done by using tracking systems attached to the animals' bodies. Remote data acquisition from animals has enhanced the knowledge about their biology and ecology. However, there is evidence that carrying biotelemetry tags affects the welfare of animal wearers and interferes with the validity of recorded data.

On welfare and scientific grounds, animal scientists have advocated for the re-design of physical and functional aspects of tags, proposing guidelines aimed at minimising device-induced impacts. However, such guidelines are dispersed and difficult to apply systematically. Hence, there is a need for an approach to systematising the design of animal-borne tags in order to minimise their impact on the wearer.

This thesis addresses such a challenge. It draws on the concept of *wearability* and proposes it as a design goal to develop devices that afford a better wearer experience (WX) for animals. The thesis develops a *wearer-centred design framework* (WCF) and applies it to demonstrate its usefulness to systematically design for good wearability.

Specifically, after the framework's elements were derived by analysing relevant information in the biotelemetry and interaction design literature, the framework was administered to teams of workshop participants who implemented it to perform a requirements analysis for a cat-tracking device. Workshop requirements served to produce a feline-centred prototype which was tested with cat wearers to investigate their experience of wearing it and thus evaluate its wearability. Outcomes show improvements of the prototype in relation to off-the-shelf devices which were tested in a parallel study. This study established a baseline for investigating a cat WX and highlighted various wearability issues with the off-the-shelf tags.

Lastly, this research demonstrates that designers can systematically design for wearability using the WCF therefore supporting the thesis that the reduction of device-related impacts is achievable.

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My last but greater appreciation goes to my family, who have lived with me all these years away from home.

To my sister Sonia, *I wish you were here.*

## **Author's declaration**

I declare that the material submitted for assessment is my own work except where credit is explicitly given to others by citation or acknowledgement.

Some ideas, figures and tables in this thesis have been published previously or are to appear for publication as reported in the following page. The study in chapter 5 is partially published in *Paci P., Mancini C., Price B.A. (2017). The Role of Ethological Observation for Measuring Animal Reactions to Biotelemetry Devices*. Parts of the study in chapter 7 is published in *Paci P., Mancini C., Price B.A. (2019). Wearer-Centered Design for Animal Biotelemetry: Implementation and Wearability Test of a Prototype*. Parts of the study in chapter 8 is to appear in *Paci P., Mancini C., Price B.A. (2019). Designing for Wearability: An Animal-Centred Framework*.



## Published work

The work presented in this thesis has led to the following publications, in chronological order.

Paci P., Mancini C., Price B.A. (2016). Towards a Wearer-Centred Framework for Animal Biotelemetry. In: *Proceedings of Measuring Behaviour 2016* (Spink, A.J ed.), 25-27 May, Dublin, Ireland, pp. 465–469.

Paci P., Mancini C., Price B.A. (2016). Designing for Wearability in Animal Biotelemetry. In: *ACI2016 Proceedings of the 3<sup>rd</sup> International Conference on Animal-Computer Interaction* (ACM), 16-17 November, Milton Keynes, UK, art.13.

Paci P., Mancini C., Price B.A. (2017). The Role of Ethological Observation for Measuring Animal Reactions to Biotelemetry Devices. In: *ACI2017 Proceedings of the 4<sup>th</sup> International Conference on Animal-Computer Interaction* (ACM), 21-23 November, Milton Keynes, UK, pp. 5:1–5:12.

Paci P., Mancini C., Price B.A. (2019). Wearer-Centered Design for Animal Biotelemetry: Implementation and Wearability Test of a Prototype. In: *ISWC'19 Proceedings of the 23<sup>rd</sup> International Symposium on Wearable Computers* (ACM), 9-13 September, London, UK, pp. 177-185.

Paci P., Mancini C., Price B.A. (2019). Designing for Wearability: An Animal-Centered Framework. In: *ACI2019 Proceedings of the 6<sup>th</sup> International Conference on Animal-Computer Interaction*, 12-14 November, Haifa, Israel. To appear.

Paci P., Mancini C., Price B.A. Evaluation of Tracking Devices and Elicitations of Wearability Requirements for Animal-Centred Wearable Biotelemetry in Cats. (Submitted to *International Journal of Human Computer Studies*. Under review).



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## 1. INTRODUCTION: Acknowledging animals as focal stakeholders in the design of biotelemetry technologies

*Biotelemetry* (or *bio-logging*) is a data-gathering practice which uses external body-attached or implanted electronic transmitters and data-loggers to remotely acquire biological data such as ecological (e.g. locations), physiological (e.g. heart rate) and behavioural information (e.g. movements) from living beings. It has a history of over half a century, during which animals, including humans<sup>1</sup>, have been fitted with trackers and sensors to study and understand their physiology and behaviour (Wilmers et al. 2015).

Particularly over the last decade, biotelemetry technology has progressed at an unprecedented rate, thanks to advances in ubicomp sensors, computational models and data management infrastructures. Typically used in medical research at its early stage, human biotelemetry has more recently become a personal daily practice, following and leading to the development of sophisticated and appealing wearable devices. This has resulted in the growth of public phenomena such as lifelogging and the ‘quantified self’ movement, in which people monitor their activities for their own purposes (Meyer et al. 2015). For many personal applications, such progress has been driven by a *user-centred approach*, whereby the continuous improvement of products is arguably motivated by the fact that people who wear the devices are also those who consent to their use, actively use them, and pay for them. In this context, *wearability* has emerged as a design goal concomitant to *usability* and has led developers to take into account design qualities such as comfortability, motor unobtrusiveness, or social acceptability (Mazilu et al. 2013).

However, humans are not the only wearers of wearable electronics. Indeed, biotelemetry has its roots in animal physiological and ecological studies from the 1950s and 1960s, when researchers fitted monkey astronauts (Hanrahan 1952) and wild bears (Craighead and Craighead 1965) with physiological sensors and animal-borne Very High Frequency (VHF) tags to study their vital parameters and movements. Since then, animal biotelemetry has advanced thanks to the availability of technologies such as Global Positioning System (GPS) satellites developed for tracking objects globally, which has provided the opportunity to track migratory wildlife, and has incentivised the monitoring of farm animals (Sikka et al. 2006) and pets (von Watzdorf and Michahelles 2010).

Although biotelemetry has contributed greatly to the study of animals, animal researchers and welfarists have expressed concerns about its growing use (Kays et al. 2015). In fact, there is evidence that carrying body-attached devices can have negative impacts on movements, physiological functions, sociality, psychological wellbeing, and even survival

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<sup>1</sup> *Homo sapiens* is obviously a species of the kingdom *Animalia*. However, to facilitate the narrative, throughout the whole dissertation, the words ‘animal’ or ‘fauna’ are used as container terms to indicate animal species other than the human one. In parallel, the words ‘human’ or ‘people’ are referred to individuals of the human species in the same way as ‘seal’ or ‘gull’ or ‘dog’ are used to distinguish individuals of their own species.

probabilities of individual animal carriers (Walker et al. 2012). For example, external tags may snag in dense vegetation (Casper 2009) or add drag in water (Wilson 2011), rub and abrade the skin, feathers or fur (Casper 2009), increase the visibility of wearers with consequent greater exposure to predators or prey (Hawkins 2004), and influence individual or social behaviour with conspecifics, resulting in abnormal behaviours such as overgrooming, desertion of brood or decreased foraging (chapter 6 in Kenward 2000).

The purpose of a biotelemetry wearable should be that of acquiring information without interfering with normal wearer's behaviours and activities, ideally producing no impacts, while yielding accurate and reliable data. The occurrence of impacts has therefore raised doubts on the validity of acquired experimental data (Murray and Fuller 2000, pp. 15-16) as well as welfare concerns (Hawkins 2004). In turn, these issues have stimulated a scientific and welfare debate on the necessity of good and acceptable practices in biotelemetry, in response to which welfare recommendations and practical refinements on equipment design have been proposed by experts in the fields of Animal Welfare and Ecology (Kenward 2000; Morton et al. 2003; Hawkins 2004; Wilson and McMahon 2006; Casper 2009; Walker et al. 2012; Hawkins 2014). More specifically, this guidance account for design details that might be important for specific animals depending on their individual characteristics and context (Jepsen et al. 2005; Wilson and McMahon 2006; Casper 2009); for example, it is recommended that a tag shape accords with the hydro- or aerodynamic body of the wearer.

Arguably, such guidelines are meant to raise awareness on the role of animals as primary *stakeholders*<sup>2</sup> of such technologies. However, although practical examples are given by welfarists for the implementation of less impacting designs, in real terms, the refinement of electronic wearables for animals has so far mainly and simply focused on the reduction of the devices' size and weight, with researchers mostly debating the generic rule that the mass of tags should not exceed the 2-5% of the animal's bodyweight (Aldridge and Brigham 1988; Jepsen et al. 2005; Smircich and Kelly 2014). This simplification of the problem may be corroborated by the fact that, in the case of animal biotelemetry, those who wear the technology (the animals) are not those who also consent to its use (typically some welfare review body or guardians), actively use it (typically researchers or carers), or pay for it (typically some funding body or human users). This arguably means that the animal wearer's requirements may not be as influential as in the case of commercial human biotelemetry. Also, guidelines and recommendations are sparse throughout different literature domains, and when at hand, are arbitrarily applied (see section 2.3.1). Thus, there is still a need for adequately representing the requirements of animal stakeholders, for

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<sup>2</sup> Stakeholders are defined by Kotonya and Sommerville (1998) as individuals "*who will be affected by the system and who have a direct or indirect influence on the system requirements*" (p. 10).

enabling the development of biotelemetry designs that are centred on the animal wearer's needs, and for systematising such a prospective *wearer-centred design*.

This research proposes to address these necessities by developing a *wearer-centred design framework*; that is, a systematic instrument for guiding the design of animal biotelemetry devices towards optimal wearability. Such a tool can arguably provide a more effective approach to designing for animal wearability in biotelemetry than the current guidelines, one that has greater potential to help researchers and designers conceive of, and develop, animal-centred devices. This hypothesis is supported by methodological research in the computer design domain which demonstrated that, by using frameworks, developers are facilitated in designing complex technological systems with which humans interact (Blackwell and Green 2003). In other words, this research aims at developing a design framework and at demonstrating that it facilitates the implementation of wearer-centred devices when the central stakeholders have not a direct say over the features of the tags they carry.

From a philosophical perspective, this work is fundamentally informed by, and consistent with, the disciplinary values of *Animal-Computer Interaction (ACI)*, an emerging field of computing whose mission is to advance research and practices related to the design of technologies involving animals, towards a full recognition of them as central stakeholders (Mancini et al. 2017).

### **1.1 Thesis statement and aims**

In his Manual for Wildlife Radio Tagging, Kenward states that “*Effects of tagging can probably never be completely avoided. The handling alone is liable to create some stress, and there has to be an energetic cost of carrying an extra load, no matter how small*” (Kenward 2000). However, although according to Kenward's assertion impacts cannot be totally avoided, we support welfarists' stance that they can be reduced. Hence, the thesis at the base of this work assumes that designing for *good* wearability means reducing the effects of tagging, thus improving the bodily experience that wearers have when wearing a tag and, consequently, their welfare. In turn, better welfare enhances the technology's capability for monitoring animals reliably, as the impacts that cause data biases are reduced.

This thesis statement is grounded on various biotelemetry studies and welfare reviews on impacts, which show evidence of tag's detriment on animal's daily life (Wilson et al. 1986) and recommend designing devices that are more consistent with the animal's characteristics (Casper 2009). Such literature highlights the physical design of a device as an aspect of biotelemetry practices that can significantly contribute to impacts on animal wearers and thus advocates wearer-centred design approaches. In doing so, it implicitly aims at achieving wearability, albeit in a non-systematic way. Hence, in order to address the problem of having a negative *wearer experience* with biotelemetry equipment, and consistent with welfare advocates' calls for animal-accordant biotelemetry design, this



research has investigated and hereby proposes a design framework that can enable biotelemetry developers and practitioners to design systematically for good wearability in animal-worn technologies.

## **1.2 Research questions: Designing in an animal-centred way**

In spite of calls for improvements by animal welfare scientists, biotelemetry practitioners have so far prioritised the miniaturisation of tags and, to some extent, the refinement of attachment methods (Kays et al. 2015) while overlooking other aspects of wearability (e.g. tag's material texture, shape, colour, etc.). Moreover, although welfarists discussed various wearability aspects of a physical device in their literature, a structured approach to designing for wearability in animal biotelemetry is still lacking. In other words, various guidelines and recommendations exist, but they are spread across multidisciplinary documentation, which make their retrieval and systematic implementation difficult. Therefore, in answer to the welfarists' calls for reducing impacts on animals by taking action on the physical design of the tags, this research addresses the problem by investigating how to design for wearability in a way that systematically accounts for the requirements of animal stakeholders during the design process. Hence, the main research question of this thesis is:

*How can wearability in animal biotelemetry technologies be systematically designed for to improve the wearer's experience and therefore reduce the impacts that the technology has on them?*

The question is addressed by deriving concepts from the biologging design literature and interrelating them to form a design-informing tool, named the Wearer-Centred Framework (WCF), that can help *designers*<sup>3</sup> to achieve good wearability for animals.

The overall research aims at developing and evaluating the WCF, which comprises four research objectives:

1. Gathering information to develop an analytical framework (the WCF) that can be applied to systematically identify relevant aspects of the wearer experience (chapter 4);
2. Investigating wearability from an animal wearer's perspective and experience (that is, in terms of impacts, stimuli, perception, and reactions) (chapter 5);
3. Establishing *wearability requirements* (that is, physical or functional aspects of a design consistent with the animals' characteristics and needs) a) through observations of cats while wearing devices (chapter 5) and b) through the application of the framework (chapter 6);

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<sup>3</sup> With the collective term of 'designers' or 'developers' it is intended whoever is responsible for the creation of a system (Gould and Lewis 1985). In biotelemetry, these people may include field biotelemetrists and ecologists, or engineers and computer designers, or a team including both specialists.

4. Validating the framework a) by comparing requirements obtained through direct observations of cats with requirements obtained through the use of the framework (chapter 6); b) by applying the requirements derived from the framework to the design of a biotelemetry prototype and by measuring the prototype's impact on animal participants to investigate improvements in their wearer experience (chapter 7); and c) by analysing the extent to which designers make use of, and are informed by the framework (chapter 8).

In order to develop the WCF and to verify whether it is a useful instrument to design for, and achieve, wearability in animal biotelemetry, three operative questions (OQs) were formulated as follows:

*OQ1: What elements might constitute such a wearer-centred framework?*

Frameworks provide designers with a set of abstract elements (such as concepts or principles) and instructions about how they work together, to help them focus the design process towards a specific goal (Preece et al. 2015, pp. 57-58). What, in this case, should be the elements of a framework that aims at achieving the goal of wearability for animals? The question was addressed by reviewing current recommendations and guidelines in wearable and biotelemetry design and deriving from them core and accessory items of the WCF.

*OQ2: How could the framework be applied during the design process?*

Prototyping is a creative and effective activity for the specification of requirements during the design process (Gomaa and Scott 1981) which can be informed by frameworks. Thus, how could the framework be used during prototyping activities to establish requirements? To answer this question, the WCF was administered to teams of designer participants, who used it during a series of workshops to heuristically establish requirements for a GPS prototype intended for use with domestic cats as a model species. Such requirements were then used during a prototyping stage in which a physical device was assembled.

*OQ3: How could the usefulness of the framework as a design-informing tool for wearability be evaluated?*

The evaluation of the WCF passed through two observational studies involving cats (study 1 and study 2) and a thematic analysis of what designers said during the workshops. Quotes were extrapolated from designers' dialogues to understand the extent to which the framework informed wearability requirements. The observational studies aimed at addressing questions such as: how can wearer experience be investigated and evaluated? What can indicate whether a design provides good or bad wearability? Which parameters (e.g. behaviours) should be measured and how?

To summarise, the general question: "*How can wearability in animal biotelemetry technologies being systematically designed*" was answered by collecting information linked

to wearability that was available in the biotelemetry literature to form a Wearer-Centred Framework and applying this during a design process. Its evaluation was fundamental to see whether the WCF usefully contributed to improving the design process towards achieving good wearability for animals.

### **1.3 Why a framework is a good approach**

The reason for choosing a conceptual framework as a way to achieve systematicity is based on Blackwell and Green's approach to *User-Centred Design (UCD)* from the designer's perspective (Blackwell and Green 2003). In UCD, the emphasis is on the users and a designer is required to interpret and apply their perspective onto a design throughout the design process. According to Blackwell and Green (2003), in order to do so, designers need to be in a position to carry out the design activities (e.g. establishing requirements) in a creative but focused way, consistent with the design goals they are required to follow (e.g. usability and user's experience goals). In some design areas, such as software development, designers are commonly guided by existing protocols, guidelines, and standards. Where at hand and applicable, such directions are usually expressed in the form of checklists to remind designers to comply with them. This is a highly structured approach developed to ensure that designers do not forget dimensions that are already known to be important. However, as Blackwell and Green state, it has various limitations. First and foremost, a design concept might not yet be defined or refined enough to be formulated as a list of instructions and related checklists, which makes this technique not applicable. In cases where some form of guidance has already been formulated, this might be scattered and/or not comprehensive, which makes guidelines and protocols inconvenient to retrieve and/or insufficient to support the designer's task. Where formulation is immature, and direction is scanty, checklists tend to be too rigid tools to stimulate a productive discussion about novel elements of a design. Furthermore, they tend to be too simplistic tools for complex designs that need to satisfy many and diverse requirements (p. 104).

In response to the limitations of checklists, Blackwell and Green propose design frameworks as conceptual and descriptive tools that are able to both inspire and scope designers towards particular aspects of a design, rather than ask them to merely apply a set of rules or guidelines that may hold creativity back and overlook important but yet uncovered aspects of a design problem (pp. 104, 106). For the authors, a framework is "*a set of discussion tools for use by designers and people evaluating designs*" (p. 106). If the aim is to enable a discussion, the kit to do so is given by core concepts, questions, principles and terms that allow designers to think about and discuss a design problem (p. 107). Basically, according to Blackwell and Green, frameworks allow designers to both systematise a design and encourage innovative thinking.

With this in mind, the research presented here focused on developing a framework, thus moving the field of animal biotelemetry design beyond the existing, and largely limited,

guidelines and checklists. As a framework, the WCF would conceivably focus designers' thinking on the goal of wearability during the design process by fostering a comprehensive discussion and supporting an articulated requirements analysis that would lead them to establish wearability requirements both in a creative and systematic fashion. In other words, the WCF was intended as a flexible resource to inspire designers while also supporting their systematic thinking during the design process, thus enabling them to account for as many animal wearability dimensions as possible. Moving from this assumption (extrapolated from Blackwell and Green 2003), this research firstly generated a framework for a wearer-centred design, and then investigated whether the WCF was a useful tool to guide and inspire designers towards designing for animal wearability.

#### **1.4 Why a framework is a necessary approach**

So far, it has been explained why a framework is a desirable and more efficient approach for designing for the complex concept of animal wearability. However, in animal biotelemetry design, such a tool is also necessary. In ACI, which commonly follows a UCD approach (more detail in section 2.3.3), (animal) users' participation in the design process to understand their perspective and experience is considered paramount (Mancini 2017). However, in the case of animal biotelemetry, wearers' involvement mostly means fitting animals with a device in order to understand their experience with it. Since, for animals, being fitted with, and carrying a device, is a source of distress, it is fundamental to reduce their direct involvement during the design process as much as possible. At the same time, consistent with a UCD philosophy, it is of paramount importance that the focus is kept on *interactors*, ensuring that they have adequate representation as the main stakeholders. Thus, taking a heuristic approach informed by a design framework that accounts for as many animals' variables as possible is a way of giving animals indirect participation and achieving animal-centred design with minimal direct involvement of wearers, particularly during the formative stages of the design.

#### **1.5 Chapter map**

This thesis is about establishing a practice of wearer-centred design for animal-borne tags. It is presented in nine chapters summarised as follow:

Chapter 2 examines core concepts, disciplinary orientations and research problems from a multidisciplinary literature including biotelemetry science, animal welfare and behaviour, and computing design. The focus is on the 'wearable' attribute of biotelemetry systems; therefore, the chapter discusses the physical design of wearable computing.

Chapter 3 motivates the methodological approach chosen, and describes the methods used for data collection and analysis within three separate phases of the research reflecting the three operative questions.

Chapter 4 presents the first research phase which aimed at developing the WCF. It presents information that matters from the perspective of animal wearers, deriving this from concepts and dimensions that are relevant to wearability, and linking them together to form the WCF.

Chapter 5 reports study 1, an observational study specifically designed for investigating animals' behavioural responses to off-the-shelf GPS tags. This served for understanding the participants' experience of wearing devices, which in turn, through the direct involvement of animal participants, provided the empirical basis for validating the WCF.

Chapter 6 describes the second research phase in which the WCF was administered to designers in a series of workshops to establish wearability requirements, which were subsequently used for prototyping a wearable tracking device. *Felis catus* (i.e. domestic cat) was chosen as model species for the first application and validation of the WCF.

Chapter 7 describes the prototyping stage, in which the requirements established during the workshops (chapter 6) were used to make a physical device, and contains study 2, a wearability study carried out with cat participants to measure the prototype's impact. Findings from this study were put in relation with the outcomes from the off-the-shelf study (chapter 5); this served as a second validation of the WCF.

Chapter 8 analyses the designers' use of the WCF during the workshops and reflects on the designers' discussions during the requirements elicitation activities to evaluate the usefulness of the WCF as an informing tool.

Chapter 9 triangulates the outcomes of the evaluations of the WCF; it discusses the contributions of this thesis to the fields of biotelemetry, ACI, and wearable design; it reflects on limitations and future iterations of the WCF; and it suggests further applications encompassing other species biotelemetry.

In the next page, Figure 1.1 illustrates the map of this research.

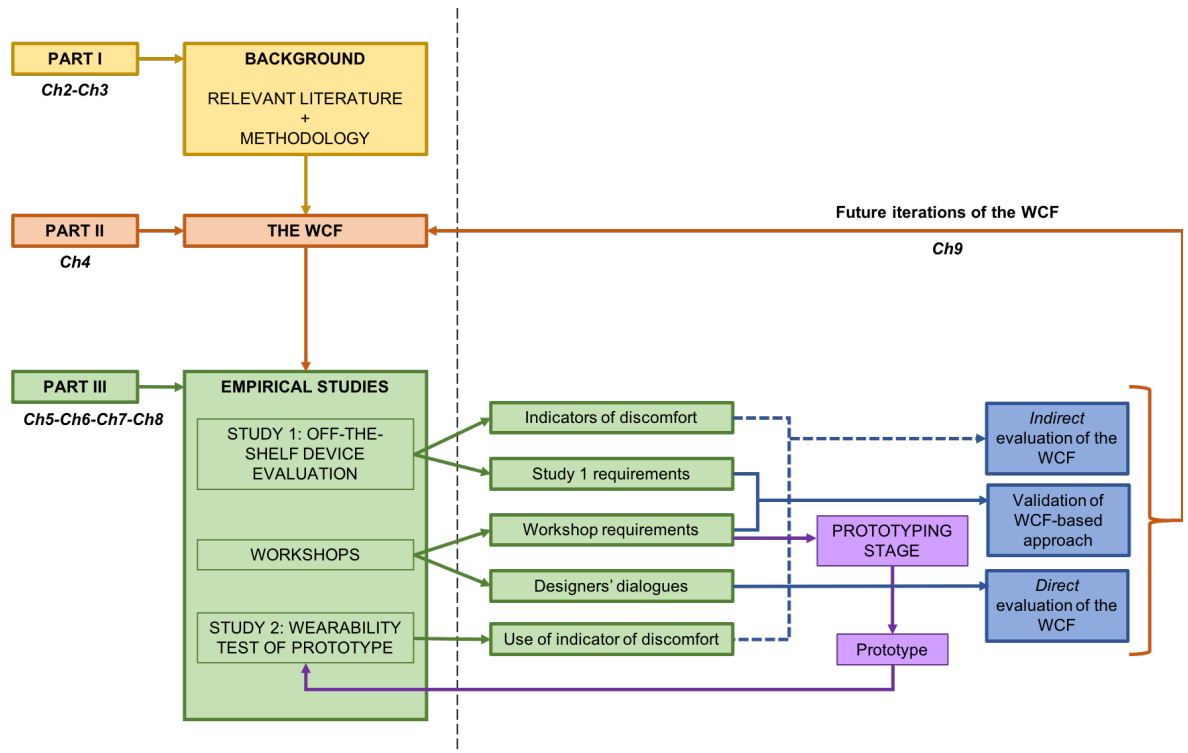


Figure 1.1: Research map showing the division of this dissertation in three parts, the content exposed in each part, the outcomes from each empirical study, how they were triangulated for the evaluations, and the prototyping stage. The heuristic approach based on the WCF use was validated to see whether it was useful. The WCF was evaluated to see how useful it was and what could be improved.

# **PART I**

## **BACKGROUND**

## 2. LITERATURE REVIEW

The following literature review is divided into four principal themes related to the main research question of this dissertation: wearability, animal biotelemetry, (biotelemetry) design, and impact reduction. The chapter's sections are organised as follows:

**Animal Biotelemetry: Technologies worn by animals** – This section introduces the practice of biotelemetry in animal biology science, describing biologging applications and technologies, thus demonstrating the wide employment of the technique and the importance of conducting this research and addressing existing design challenges.

**Impacts of biotelemetry on animals** – This section discusses the welfare and scientific issues related to the impacts produced by wearing a device. Animals are affected by the obstructive nature of body-attached tags, which produce alterations of their behaviour, physiology, and physique. These impacts raise two main problems: the lessening of animal welfare (due to detrimental body-device interactions), and the risk of obtaining device-biased data (consequent to behavioural, physiological and physical alterations). This section provides critical information to understand these problems and why it is important to address them.

**Design approach to animal biotelemetry** – This section firstly discusses the commonplace design approach based on guidelines that has been proposed by welfarists, and broadly followed by biotelemetry practitioners, to limit the impacts. The section then identifies the limitations of using guidelines, including their dispersity and unsystematic use, and challenges in understanding an animal's perspective. To address these limitations and find a way forward, the section also identifies a) a commonality with design philosophies such as User-Centred Design (UCD) and b) a fitting role for design instruments such as frameworks. It then frames this research within the computing discipline of Animal-Computer Interaction (ACI), discussing the interest of ACI for animal-centred design but also a new perspective to the application of UCD as currently envisaged by ACI. Overall, the section defines the gap in the field, which relates to the design of biotelemetry tags in a systematic way that is consistent with the animal perspective. Consequently, the section introduces the research problem of what to investigate in order to fill the gap, pointing to a new design approach in biotelemetry that focuses on wearability.

**The concept of wearability and wearable design** – This section illustrates early and more established frameworks and empirical studies of wearable computing for both humans and animals, exploring the wearability criteria for borne devices. It defines more precisely the research problem exposing the concept of wearability as the central issue of this dissertation. It argues that, while in the design of animal worn devices wearability has begun to be addressed, the notion is still emerging and mostly investigated in relation to human wearables; hence, it needs to be further developed and its role in animal



biotelemetry design needs to be promoted. Thus, the section explores further the knowledge gap when it comes to designing unobtrusive animal wearables, identifying systematisation as a key issue.

**Conclusions of the literature review: Designing for wearability** - The need for systematicity when approaching the design of animal wearables, along with the need to consider wearers as primary stakeholders, motivated the focus on wearability taken by this research with regards to the design of body-attached tags. This led to the development of a design framework centred on (animal) wearers rather than (human) users, to inform the design of animal-centred biotelemetry wearables.

A literature map summarising the literature review is provided with Figure 2.1.

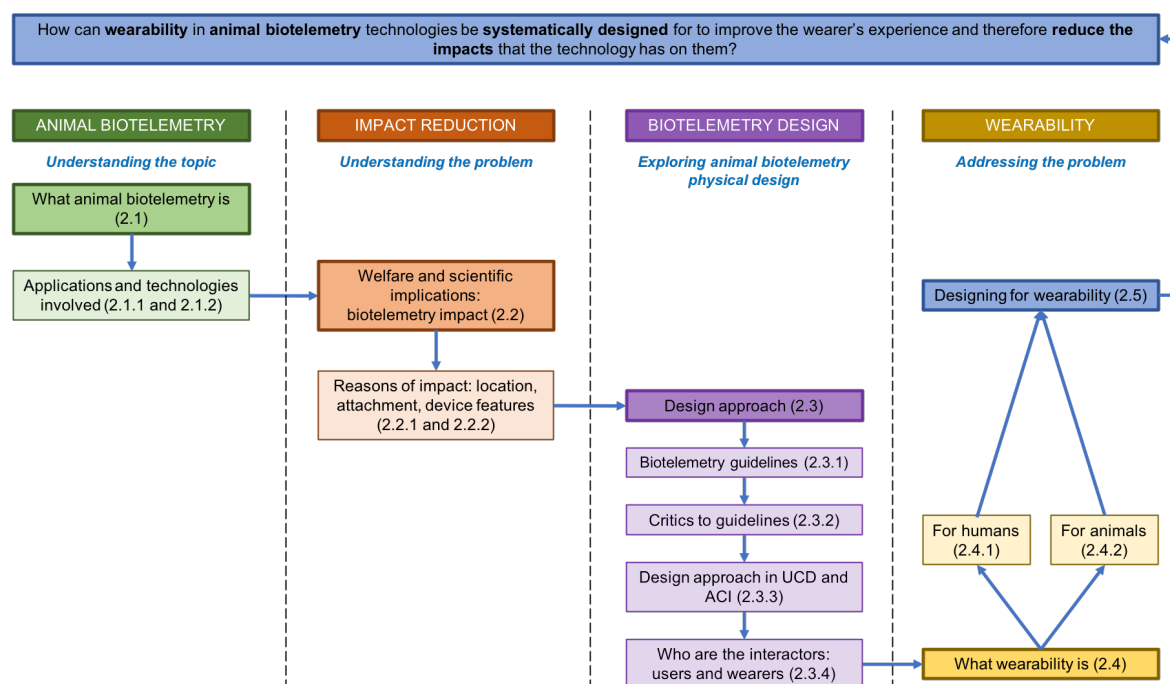


Figure 2.1: Literature map summarising the literature review.

## 2.1 Animal biotelemetry: Technologies worn by animals

Animals have been remotely monitored by means of biotelemetry<sup>4</sup> devices such as electronic trackers, activity monitors, or physiological sensors since the 1960s (Wilmers et al. 2015). Radio collars were among the first devices carried by feral animals for analysing their movement patterns otherwise difficult to study in the wild (Craighead and Craighead 1965). Starting from the 1980s, the development of products exploiting satellite platforms has broadened the application of the biotelemetry technique to the monitoring of wide-ranging animals and migratory species (Wilmers et al. 2015). More recently, telecommunication technologies have been exploited for the tracking of domestic animals where a varied range of products have been sold on the market to satisfy the need of pet carers who are worried about losing their companions when these are allowed to roam outside their homes (von

<sup>4</sup> Biotelemetry literally means biometric measurements at a distance.

Watzdorf and Michahelles 2010); or who are interested in quantifying how active their pets are, finding out if they tend to have too sedentary a life and trying to change this tendency<sup>5</sup>. In this respect, phenomena like lifelogging or ‘quantified self’ with pets have become a new trend among handlers worried about the safety and health of their animal companions (Ahn et al. 2016).

Biotelemetry technology has been also used with farm, laboratory and working animals. For example, tracking systems can help farmers monitor the location of their livestock grazing outside paddocks (Sikka et al. 2006); wireless sensors for recording physiological parameters are implanted or attached to the body of laboratory animals to provide a continuous flow of data without restricting the individuals (Liu et al. 2015; Niemeyer 2016); trackers embedded in vests developed for rescue and assistant dogs help locating them when they patrol impervious territories or perform their assistive tasks (Komori et al. 2015).

Overall, tracking animal movements and measuring their vital parameters by means of biotelemetry instrumentation has improved humans’ insight into the ecology of a wide range of species; it has allowed the development of tailored wildlife management strategies (Cooke 2008) and the refinement of laboratory procedures (Hawkins 2014), as well as care-taking practices of farm (Hamrita and Paulishen 2011) and companion animals (von Watzdorf and Michahelles 2010).

Figure 2.2 illustrates some of these technologies used on various animal categories such as wildlife, pets, and farm animals.



*Figure 2.2: A sampling of GPS devices available on the biotelemetry market.*

The above-mentioned examples indicate that remote monitoring systems have become ubiquitous as they are used in many human activities ranging from pet caring to wildlife research. Hence, many animal individuals are involved in biotelemetry practices and many others will be since the science is further growing thanks to advances in technological development (Kays et al. 2015; Wilmers et al. 2015). The more the field grows the more awareness about animals’ involvement arises and, with it, concerns about their welfare. Since animal biotelemetry concerns species other than humans, peculiar aspects of the practice need to be acknowledged, these being distinct from practices related to human

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<sup>5</sup> Examples of products sold online can be found on: (G-paws.com; Kippy.eu; Pawtrack.com; Tractive.com).

biotelemetry (for example, animals have to be captured and restrained so that tags can be fitted on them).

To highlight biotelemetry issues and challenges due to the species-specific characteristics and lifestyles of animals, which have implications for the design and employment of tags, the next two sections (2.1.1 and 2.1.2) briefly overview the state-of-the-art in animal biotelemetry. To navigate the vast field of biotelemetry, the relevant technologies are reviewed by following the distinction proposed by Kenward (2000), who divides them in electronic tracking (whereby positions and movements of free-ranging individuals are charted by means of body-carried radio- or geo-locators) and bio-sensing (whereby behavioural, physiological, and environmental parameters of both confined and free-living animals are logged through sensors connected to the body). Such categorisation was chosen in view of the implications that the instrumentation has for the wearer. Typically in tracking, impacts are mostly related to the sizeable bulk of tags, which depends on the significant battery usage required by long-range broadcasting of satellite signals. Conversely, bio-sensing relies on miniature bio-loggers, but it mostly produces impacts due to the retrieval of data through physical animal recapturing. This leads to the discussion, in subsequent sections, of the impacts produced by the devices (2.2) and of the related design implications (2.3).

#### **2.1.1 Tracking: Advantages, constraints, drawbacks**

Tracking is the biotelemetry technique conventionally used to investigate ecological dynamics (e.g. home range, habitat use, population estimation, migration, mortality, social interactions, etc.) in wildlife (Kays et al. 2015). Knowledge of these dynamics informs conservation strategies in threatened and endangered species or management solutions that foster a compatible coexistence between ranging animals and humans. For one example, wild animals may cross interurban roads and highways that cut their pathways; consequently, they may collide with vehicles risking their life and that of human drivers. Animal tracking systems allow researchers to map the animals' usual passages and accordingly build ecological corridors, such as tunnels and bridges, that allow the animals to pass beneath or above roads (Maletzke et al. 2005).

More recently, tracking has been used within the management of farm animals (e.g. to locate and reduce losses among grazing herds (de Weerd et al. 2015)), working animals (e.g. to monitor the work of search and rescue dogs (Komori et al. 2015)) and domestic animals (e.g. to investigate roaming habits of outdoor cats (Hervías et al. 2014)).

The three main technologies used for tracking animals (Figure 2.3) include radio telemetry, such as Very High Frequency (VHF), and satellite systems, such as the Advanced Research and Global Observation Satellite (ARGOS) and Global Positioning Systems (GPS).



Figure 2.3: Graphic representation of the three main technologies used for tracking animals. VHF tags convey radio signals picked up with an antenna; position is obtained through triangulation. ARGOS devices send Doppler Shift signals to the satellites which transmit the signal back to a user computer. GPS loggers receive signals from the satellites and store them into their internal memory; loggers need to be retrieved in order to download the data into a computer (© 2016 [www.sirtrack.co.nz](http://www.sirtrack.co.nz)).

Each of these technologies has functional advantages and disadvantages. Albeit an older technology, VHF has been favoured for ecological studies particularly with small animals. The tags require little energy and therefore run on small batteries, which makes them very small and light (12 x 5 x 2 mm, 0.19 grams for 5 days lifespan<sup>6</sup> – in: (Habib et al. 2014)), as well as inexpensive.

However, whilst VHF tags are cheap and light, various practical and procedural drawbacks limit their employment. For example, locating individuals in their environments is a labour intensive and costly process, which requires the presence in the field of an operator for long hours to control a receiving antenna. This also alerts animals, which may flee or hide for a long time in response to human disturbance. These induced behaviours are recorded, adding biases during data acquisition. For example, individuals may go beyond their habitual territory to avoid human presence, resulting in an unreliably wider home range.

Additionally, the VHF detection distance is limited, which precludes its use with wide-ranging species. The range depends on the shape and length of the transmitting aerial, which is a device component attached to the animal. Antennae are an element of obstruction for wearers if mounted externally to the devices encase (e.g. whip type); they can alter animals' movements and activities, adding further biases. Additionally, the radio signal is vulnerable to variations in topography (which diffract wave propagation), vegetation or weather, which limits the effectiveness of VHF in mountainous or wooded environments.

In contrast, ARGOS does not suffer from signal vulnerability. Theoretically, it enables global tracking in almost real-time, sending acquired information directly to the user's computer. For this reason, it is particularly used with marine wildlife (Costa et al. 2010), which is arduous to track manually.

However, while the technology virtually eliminates labour costs and operator disturbance, the tags are expensive and using the satellite service incurs fees. Moreover, the location accuracy is poor compared to VHF and GPS (Habib et al. 2014) and compared to VHF tags the devices are heavier so they cannot be used on small animals.

<sup>6</sup> [http://www.biotrack.co.uk/update\\_pip.19.php](http://www.biotrack.co.uk/update_pip.19.php) (accessed 30 January 2019)

GPS is another global tracking system, but in contrast to ARGOS it is also very accurate (circa 5 m radius) under open sky (Rempel and Rodgers 1997). Therefore, it is suitable for studying with precision the movements of wide ranging and migratory animals. It has also become popular for tracking domestic companion animals (von Watzdorf and Michahelles 2010).

However, since the signal is undetectable from under-water and underground, and is inaccurate in thick vegetation, GPS is not suitable for tracking marine, burrowing or dense woodland animals, except if and when they surface. This problem has partially been solved by combining traditional GPSs with the Fastloc® location technology, which is a signal snapshot receiver able to acquire a satellite wave in less than 60ms (Rutz and Hays 2009). However, although the technology virtually incurs no fieldwork costs, the devices are expensive. They are also power-hungry which increases the weight and size of the devices, making them unsuitable for small animals, and also shortens battery life, making them unsuitable to study wild animals for long periods.

Conversely to ARGOS tracking, GPS is a receiving technology that stores the inputs transmitted by the satellite into the internal memory of the GPS unit. In order to download the data, end users (e.g. researchers, pet carers, farmers) have to either retrieve the device by recapturing the animal or add data transmitters to the GPS element. Both these measures for recovering the data have disadvantages. On the one hand, chasing and recapturing wild animals is highly stressful for them, impinging on their psychological and physiological wellbeing (Wilson and McMahon 2006). On the other hand, transferring data wirelessly from the GPS module to a receiving station requires additional transmitting components which increase both weight and extra battery usage of the GPS unit (Habib et al. 2014).

Nevertheless, remote data retrieval standards and services such as the Global System for Mobile communications (GSM) and the General Packet Radio Service (GPRS) are regularly integrated in the current generation of GPS units since the benefit of not-recapturing overcomes the extra load and battery drainage drawbacks, while enabling accessory functions, such access to data in real-time and immediate response to targeted animal behaviours. For example, cell-phone technology can be used to access an animal's location by sending an SMS (Short Message Service), or to set 'virtual fences' which notify users when tracked individuals cross a pre-defined border (e.g. pets who move far from home, or wildlife who trespasses human settlements) (Kays et al. 2015).

The high heterogeneity in shape, size, behaviour and environment of different animal species makes the development of one-size-fits-all tracking device currently unfeasible (Markham and Wilkinson 2008). Therefore, all the technological solutions developed over the past 60 years are in use today and choices about their deployment are made based on specific contextual and technical constraints such as size, environment, mobility and sensitivity of the animal, energy consumption and harvesting, tag costs, data retrieval, and

signal capture and accuracy. This implies three necessary requirements for biotelemetry devices: they must adapt to animals, deliver usable and low-cost data to humans, and reliably work for the time and place they are employed.

To optimally meet such requirements, hybrid solutions, combining various wireless and mobile phone networks with radio and satellite tracking systems, have been developed through collaborations between biologists and computer engineers. For example, the ZebraNet project delivered GPS collars equipped with wireless transceivers (i.e. a combined device that both transmits and receives radio signals) which work as a peer-to-peer network to monitor zebras in open lands (Juang et al. 2002); the Electronic Shepherd system integrated GPS receivers, UHF (Ultra High Frequency) radio transceivers, and GPRS modems for tracking high-pasture sheep (Thorstensen et al. 2004); the EcoLocate system fused together GPS and VHF technologies to create a wireless network for monitoring mammals of a wide size-spectrum in the Savannah (Markham and Wilkinson 2008). On the pet-consumer market we are witnessing the same trend. At the time of writing, various manufacturers provide GPS, GSM, GPRS, GloNaSS (Global Navigation Satellite System) applications, or various combinations of them, for devices specifically designed to be used on pets. Many examples of such products can be found online (Kippy.eu, G-Paws.com, Tractive.com, Pawtrax.co.uk, Pawtrack.com).

However, on the whole, both single and hybrid solutions are devised paying great attention to technological capabilities and user's data-gathering needs, while merely adapting the tags to target animals in terms of miniaturisation. Shrinking the device size is certainly a priority for animal biotelemetrists who seek to gather good data from unswayed animals of any size (Kays et al. 2015); indeed, tag conspicuousness is a primary factor that burdens animal carriers and limits the applicability of the technology to medium-to-large-sized animals. However, the challenge of designing adequate biotelemetry technologies concerns more aspects of the animals' life and needs than solely their size.

### **2.1.2 Biosensing: Advantages, constraints, drawbacks**

While tracking is the common technique used for monitoring relatively accurate location and movements of animals, biotelemetry transducers (i.e. devices that convert physical quantities such as pressure into an electrical signal, and vice versa) are used to measure their physiological status as well as various behavioural, energetics and environmental parameters for a range of purposes within medical research or conservation practices (Güler and Übeyli 2002).

Miniature biosensors such as temperature recorders or pressure loggers are widely used in biological research to accurately detect physiological parameters such as heart rate, respiration rate, blood flow and pressure, blood oxygen levels, and body temperature both in laboratory animals and wildlife. Bio-loggers such as tri-axial accelerometers allow users to measure changes in movement (e.g. from stationery to walking) or orientation of body

parts (e.g. head tilting) by reacting to the earth's gravitational field (Wilson et al. 2008). In particular, accelerometers and gyroscopes are the sensors employed in pet health and activity monitors currently in vogue among pet carers (Ahn et al. 2016). UHF-RFID (Ultra High Frequency-Radio Frequency Identification) proximity loggers are used for studying social and interactive behaviour among conspecifics (e.g. Prange et al. (2006) studied their application on free-ranging raccoons). Neurologgers are EEG (Electroencephalography) recorders able to detect changes in neuronal activity and are used, for example, with homing pigeons to study how they recognise landmarks during flight (Vyssotski et al. 2009). Particularly on marine birds and mammals, accelerometers and Time Depth Recorders (TDRs) are used to collect a wide range of energetics parameters such as muscle activity, swim speed, diving depth and duration, flipper stroke frequency, jaw or beak movements, and other rare behavioural events (such as prey captures). For example, TDRs were used for recording the diving behaviour and time budgets<sup>7</sup> of seabirds in order to estimate their prey requirements and submerged catch rates (Harding et al. 2009). Multi-sensor archival devices have been developed for use in a wide range of wild animals. For example, the Daily Diary (DD) device incorporates tracking technologies and biosensors able to log data for up to 14 parameters (Wilson et al. 2008).

As an alternative to tracking (which aims to map movement paths of individuals with accuracy), the coarser localisation of an animal in an area of interest (for example, if and how many times some individuals visit a certain spot) is possible thanks to less obtrusive technologies. These are typically designed for particular species or habitat conditions. For example, individuals marked by a microchip can be detected in certain sites through RFID systems or camera traps. This is particularly applicable with territorial animals who have defined home range and habits (e.g. badgers dwell in stable burrows and visit regularly fixed spots such as latrines (Dyo et al. 2010)). Approximate tracing of flyways by means of miniaturised light-based geo-locators (i.e. archival trackers that record solar irradiance to determine location) is also employed for studying the diurnal flight of migratory animals, where the use of satellite methods is not advisable, as is the case with small migratory birds (Lisovski et al. 2012). Finally, animals also wear bio-loggers for purposes other than the monitoring of their biological parameters. Oceanographic data-logger applications use wildlife as sampling mobile stations for the remote monitoring of environmental conditions around the animals (for example, humidity, ambient temperature and water salinity (Wilmers et al. 2015)).

Figure 2.4 shows a selection of these bio-sensors: a) Daily Diary logger, b) neurologgers, c) UHF-RFID, and d) TDR loggers.

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<sup>7</sup> Time budget is about recording the amount of time devoted by the animal for *their* usual activities (e.g. sleeping, resting, foraging, pecking, etc.)





Figure 2.4: A sampling of bio-sensors: a) external design and description of the direction axes of a Daily Diary (DD) logger (© [www.wildlifecomputers.com](http://www.wildlifecomputers.com)); b) neurologger partially implanted in a homing pigeon's skull for studying spatial cognition of the species (Vyssotsky et al., 2006); c) UHF RFID proximity tags attached through perforation on cattle ears for identifying them (© [www.rfidreaderuhf.com](http://www.rfidreaderuhf.com)); d) Time-Depth Recorder (TDR) logger attached on the back of a beaked whale by means of a suction-cup (© [www.savethewhales.org](http://www.savethewhales.org)).

The logging of a wide range of biological data is enabled by relatively cheap, miniaturised, and lightweight transducers, which are highly desirable qualities both from the perspective of usability and wearability. Such tag properties have encouraged the usage of body-attached devices on several fauna for studying the intimate life of individuals and have broadened the purposes of tracking, while reducing the load on wearers. However, particularly for free-ranging animals, bio-sensing tags have been increasingly integrated into tracking devices (Kays et al. 2015) or have been clustered together in multi-sensor units, such as the DD (size  $55 \times 30 \times 15$  mm; 42 g – (Wilson et al. 2008)). This has provided the advantage of maximising the quantity and quality of data collected through single devices or interventions (Rutz and Hays 2009), but has also taken away the benefit of using small light-weight devices employing single small-scale sensors (Matthews et al. 2013). Moreover, typically, biosensing data is stored locally in the memory of the devices, which therefore need to be retrieved. While this is relatively easy to do with confined animals, thanks to the use of equally small short-range radio transceivers, data-retrieval in wide-roaming animals remains an issue, requiring the use of more expensive and obtrusive transmitting technologies, such as ARGOS, GSM and GPRS modules, or stress-inducing practices, such as physical re-capturing. Hence, although miniaturisation is again considered the feature most capable of enabling a ubiquitous use of animal biotelemetry, in practice animal-attached devices are still bulky, since multiple smaller components are combined in single devices to maximise the gathering of various data, or to monitor the life of ever smaller species instead of decreasing the relative mass of attached tags (Portugal and White 2018).

Overall, a main concern in biotelemetry design has been that of shrinking the device weight and size for both the advantages of monitoring small animals and of reducing biotelemetry-induced impacts (Kays et al. 2015). With regards to impacts, device mass has been deemed to cause effects ranging from energetic extra-expenditure (Wilson et al. 1986) to decreased



flight manoeuvrability (Aldridge and Brigham 1988); therefore, miniaturisation has become a crucial goal. However, although miniaturising tags is certainly a primary way of reducing the burden that animals carry on their bodies, this is not the only design aspect that should be taken into consideration during design. To understand which other factors impinge on wearers and, therefore, need to be taken into account when designing, the next section discusses the welfare implications of wearing biotelemetry devices, exposing the impacts derived from a wider range of device features than just their weight.

## **2.2 Impacts of biotelemetry on animals**

The use of remote measuring technologies has become ubiquitous across wildlife and laboratory research fields as well as caretaking practices, with widespread benefits. For example, it has yielded insights that have led to the protection of endangered species, to the refinement of experimental procedures on laboratory animals, or to the retrieval of lost pets. However, there is evidence that carrying biotelemetry devices can influence the wearer's physiological parameters and disrupt behavioural patterns that are important for survival, sociality, and reproduction. For example, Lameris and colleagues (2018) found that migratory monogamous waterfowls fitted with harness-mounted tags had a lower return rate in their usual nesting area than unfitted individuals (who were only ring-marked). This was found to be most likely due to device-reduced survival, which affected pair-bonding and thus breeding (Lameris et al. 2018).

Especially in wildlife research, such impacts interfere with the phenomena that are being monitored and therefore bias the accuracy and reliability of acquired experimental data (Murray and Fuller 2000, pp. 15-16). For example, Wilson attached speed meters on penguins to monitor their foraging behaviour; he concluded that the devices had increased drag during swimming, reducing the speed and consequently influencing the catching prey rate he wanted to study (Wilson et al. 1986). This kind of interference corroborates concern regarding the suitability of the biotelemetry technique as a research tool. In a study on seabirds, Harding confirmed her awareness that "*data obtained from loggers may not represent the natural behaviour of the species*" (Harding et al. 2009); although her findings did not show negative effects of TDRs on little auks (a seabird species), she concluded that more studies are needed to determine device-induced impacts. In a more recent work, Wilson affirms that "*it is essentially impossible to 'tag' an animal without changing its state*" and therefore he investigates metrics derived from accelerometers that can be used to assess the extent to which 'tagging' affects research findings (Wilson et al. 2018).

Data biased by the device presence is certainly an issue. However, the use of such devices has raised also ethical concerns about the reduction of individual wearers' welfare (Morton et al. 2003). Depending on the degree of obtrusiveness and disruption of biotelemetry interventions, which depends on the type of equipment involved, the technology can have more or less severe adverse effects on animal wellbeing (Walker et al. 2012).

To begin with, most of the animals need to be captured and physically restrained in order to attach or retrieve devices. Especially for individuals not habituated to human handling, such as wildlife, capture and immobilisation are extremely stressful operations, comparable to being captured by a predator (Wilson and McMahon 2006). Short or long-term physiological and psychological alterations, as well as injuries sustained in an attempt to break free and escape, are serious consequences of such procedures (Wilson and McMahon 2006).

After capturing, devices can be externally attached or implanted (partial or total insertion). Epidermis perforation or surgery is needed in case of sub-cutaneous injection or abdominal cavity implantation. Pain and discomfort in surgical interventions are not avoidable, even when pain relief is administered (Morton et al. 2003). Logger implantation, usually associated to laboratory practices, is not uncommon also in wildlife tagging, in which case asepsis and after-surgery treatments are more difficult, and infections or wound breakages are more likely complications (Morton et al. 2003; Hawkins 2004).

However, beyond the more evident impact caused by capture and implanting surgery (which is beyond the scope of this research), the *very fact of wearing* biotelemetry tags can be obtrusive for an animal, causing physical and behavioural interferences (Walker et al. 2012). For example, individual or social behaviour with conspecifics may be influenced, resulting in abnormal behaviour such as preening directed at the device (e.g. Hooze (1991) found it on woodpeckers), neck constriction (e.g. Garshelis and Siniff (1983) observed it in collared sea otters) or divorce between monogamous birds (e.g. in waterfowl studied by Lameris et al. (2018)).

A broad gamut of detrimental experiences related with the bodily interaction between the device and the animal are reviewed in the biotelemetry literature, which stresses the central problem of impacts afflicting the practice. Various authors report that tags can increase energetic costs, obtrude movements or obstruct access to locations, and cause physical or psychological harm such as abrasion, pressure sores, or abnormal grooming (Kenward 2000; Walker et al. 2012; Matthews et al. 2013). Mech and Barber list impacts for birds such as “*antennas and attachment packages becoming snagged in vegetation, animals themselves becoming entangled in loose collars or harnesses, chaffing or feather loss, electrocution in birds fitted with whip antennas while perched on wires, increased drag when swimming, lifting, or flying*” (Mech and Barber 2002, p. 30). (Other listed impacts can be found in other works such as Kenward (2000, p. 124) or Murray and Fuller (2000)). Generally, disruption is related a) to the location and method by which the device is attached, and b) to the features of the device itself (Murray and Fuller 2000, p.30). Hence, the next two sections (2.2.1 and 2.2.2) link each impact to one or both design aspects of the device (i.e. location and method of attachment, and/or tag features).

### 2.2.1 Impacts due to location and method of attachment

Devices are fixed to different parts of the body and with different methods depending on the morphological and behavioural characteristics of animals. Figure 2.5 shows some of these methods and locations of attachment: a) collar; b) shoulder blade harness; c) and d) glue on feathers and carapace; e) leg strip; f) flipper attachment.

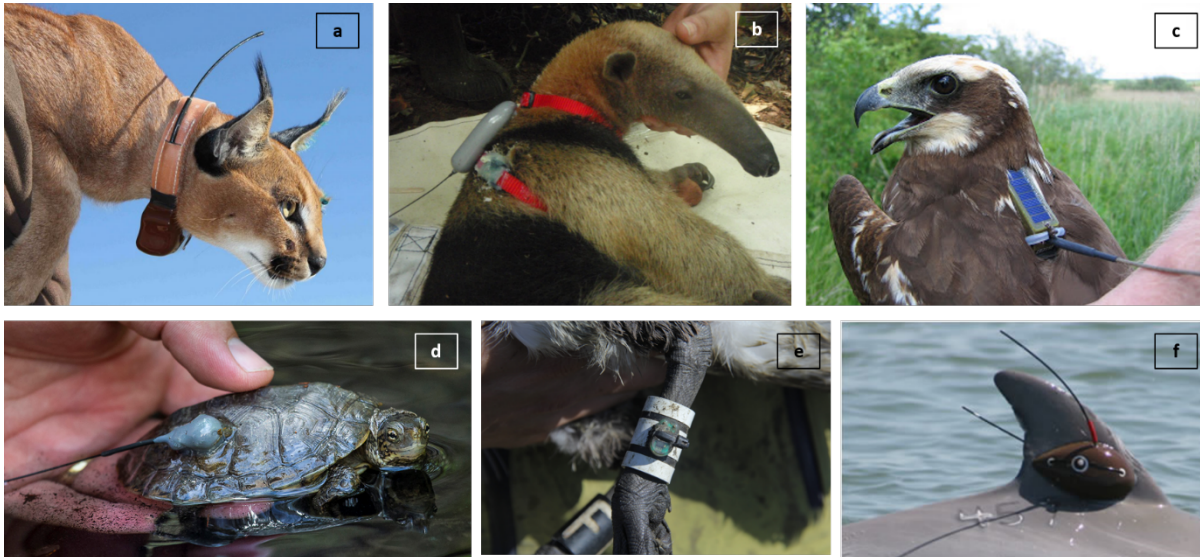


Figure 2.5: A sampling of methods and locations of attachment:  
a) Collar on a caracal (© <https://cheetahkids.wordpress.com/>),  
b) Harness on an anteater (© <https://agoutienterprise.wordpress.com/>),  
c) Satellite tag glued on a marsh harrier (© <http://animalmovement-canmove.blogspot.co.uk/>),  
d) Transmitter glued on a turtle shell (© <http://blogs.sandiegozoo.org/2015/01/17/>),  
e) Leg strip on a goose (© [http://tobseda.com/?page\\_id=166](http://tobseda.com/?page_id=166)),  
f) Flipper mount on a dolphin (© <http://www.sefsc.noaa.gov>).

Location and mounting impacts are described widely in the literature in various review papers, including: (Kenward 2000; Murray and Fuller 2000; Morton et al. 2003; Hawkins 2004; Casper 2009; Walker et al. 2012, Lameris and Kleyheeg 2017), and can be summarised as follows:

Collars, necklaces and pendants may cause overloading and imbalance of the body (e.g. in: Hawkins 2004). Tight collars may cause neck constriction. Mandibles may get stuck in loose collars (e.g. in: Lameris and Kleyheeg 2017). Stiff neckbands may cause hair loss under the collar, abrade and damage the neck skin (e.g. in: Kenward 2000). Strangulation may also ensue for juveniles wearing rigid young-size collars as they grow (e.g. in: Casper 2009). Also, under freezing temperature, ice may accumulate on plastic collars (e.g. in: Lameris and Kleyheeg 2017).

Harnesses, backpacks and jackets may add compression and weight on the vertebral column causing pressure sores, especially if fastened tightly (in: Morton et al. 2003). They may also get caught in dense vegetation, burrows or marine debris (e.g. fishing nets), trapping wearers. Growth of young or feed shortages mean that fitted harnesses may become too tight or too loose. Backpacks may hinder moulting, disrupt waterproof plumage, or cause

drag (e.g. in: Casper 2009). Skin or feather abrasion and infection may also occur (e.g. in: Kenward 2000).

Glue and tape used to attach devices onto skin, fur or feathers may induce coat loss or difficulty in shedding at the site of attachment, impeding regular insulation or disrupting body waterproofing (e.g. in: Kenward 2000). Glues may contain compounds that generate heat when applied to the skin, which may cause skin burn and irritation (e.g. in: Casper 2009).

Limb or other extremity attachments such as leg strips, ankle bracelets, patagial (i.e. thin membrane between the body and the limb, typical in bats and birds) and wing mounts, flipper harpoons (on cetaceans and large fish), and tail mount may restrict movements, produce swelling or add drag that modifies normal locomotion (e.g. flying and swimming) (e.g. in: Murray and Fuller 2000; Walker et al. 2012).

Piercing, sutures or skin perforation (e.g. through ears or fin skin) may cause infection on the site of attachment and tissue damage. Sutures can be scratched causing bleeding that entices predators. Screwed bolts and tethers attached through drilled holes in tortoise shells may cause hydrodynamic drag and entanglement (e.g. in: Hawkins 2004).

### **2.2.2 Impacts due to the features of the monitoring device**

In addition to location and method of attachment, the physical characteristics of a device can affect the wearer as follow:

The weight of devices may increase energetic costs for animals with subsequent body mass loss or decrease of survival probabilities (Godfrey et al. 2003; Wilson and McMahon 2006).

Improper shape and length of tags may cause discomfort or pain due to pressure on internal organs and meddling with postures (e.g. curling) (Hawkins 2004). The silhouette of the body may be expanded interfering with spatial motion, especially on burrowing species; components such as external antennae can get stuck in dense vegetation (Kenward 2000), add drag in water (Wilson and McMahon 2006), or even provoke unexpected, though possible, events such as electrocution (Dunstan 1977).

Hard and stiff encapsulating materials of the electronic components may rub on skin, fur or feathers causing abrasion or wounds (Casper 2009). Broken parts of the box tearing off when chewed by conspecifics or predators may cause suffocation (Soderquist and Serena 2000).

Colours of cases, contrasting with natural colours of animal coats, can increase the visibility of wearers with consequent greater exposure to predators or prey (Hawkins 2004) or human hunters (Mech and Barber 2002, p. 31). Tinted tags may cause bemusement during mate selection, especially in those animals who, like birds, choose partners according to plumage pigmentation (Burley et al. 1982).

Transmitting modules may emit acoustic frequencies which can expose them or distress sensitive animals if the (ultra)sound is audible to them (Casper 2009).

Although this is an extensive array of impacts, according to Casper and Walker et al., the majority of the studies exploiting biotelemetry technologies do not report backlashes (Casper 2009; Walker et al. 2012). When they do report any, side effects are often considered mere occurrences instead of proper findings and usually are not investigated further. Vandenabeele et al. (2011) analysed 357 publications released between 1986 and 2009 on seabird tagging. Only 42 of those (11.8%) had the assessment of instrumentation effects as a primary research objective. These mainly focused on testing impacts on foraging, breeding, and diving behaviour, physical condition, time budget<sup>8</sup> and energetics. Many other impacts might have never been reported or properly studied, which means that wearers' welfare might be poorer than researchers think.

Clearly, the impacts discussed above highlight the importance of reducing them, to obtain unbiased data and achieve wellbeing improvements, whereby data quality can only increase as a result of improved welfare (Väätäjä and Pesonen 2013). Indeed, animal welfare is regulated by international and national legislation, which sets certain protections for the individuals involved in research or in management procedures (e.g. European Commission Directive 2010/63/EU 2010; U.S. Congress Animal Welfare Act; UK Parliament Animal Act 1986). Thus, accounting for animal welfare is also, and foremost, a legal requirement, which adds significance to the matter.

Over the years, designing device components so that their features limit their negative effects as much as possible has become a common objective for animal welfare and conservation scientists, who have proposed various practical guidelines that assist best practices in the physical design of tags (Kenward 2000; Morton et al. 2003; Hawkins 2004; Wilson and McMahon 2006; Casper 2009; Lameris and Kleyheeg 2017).

In the next section, existing recommendations for limiting the impacts of biotelemetry are discussed further to highlight their limitations, and to introduce standards explicitly concerned with the wearability aspects of body-attached gadgets.

### **2.3 Design approach to animal biotelemetry**

Designing devices that impinge less is a complex endeavour that requires knowledge about both biological and technological aspects at a minimum. On the strength of such knowledge, animal welfarists and biotelemetrists have proposed design standards related to the very fact of wearing biotelemetry tags, to the physical design of attachment and hardware components, and to the choice of the location of attachment.

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<sup>8</sup> For 'time budget', Vandenabeele and colleagues (2011) refer to "*the proportion of time allocated to normal activities compared to device-induced behaviours (pecking, excessive preening or other comfort behaviours, such as flapping or bathing, nest desertion)*".

### 2.3.1 Design guidelines in animal biotelemetry

The most commonly reported and debated design guideline is the so called ‘5% rule’ (or 2%, or 3%), according to which the weight of the tag should not exceed a certain percentage (2% or 3% or 5%) of the animal’s body weight. Such standards originated precisely to employ lighter tags in order to reduce the impact associated with too heavy a load. However, beyond the fact that there is not even agreement on the percentage itself, various studies have challenged this rule and showed that it is too coarse a measure. For example, Aldridge and Brigham (1988) tested it by studying the flight manoeuvrability of bats fitted with tags. Since the ratio of 5% between animal body and tag mass is a fixed value, heavier individuals were fitted with heavier tags. The authors found that, in comparison with lighter bats, heavier tags correlated with a higher decrease in the heavier bats’ ability to make sharp turns. The assumption implied by the rule is that a heavier body can carry a heavier load. However, the muscular power that allows a volant animal to fly does not get enhanced by the tag. Since flying movements necessitate higher muscular power to move heavier bodies, the author concluded that a heavier extra load impinges more on flight behaviour and thus suggested that the rule ought to be applied on a case basis (Aldridge and Brigham 1988). From this, it could be argued that the rule needs to be refined, for example, by accounting for other variables in addition to body mass, such the kind of movement made by the wearer (flight) and the proportion of muscles available to perform that movement.

After the work of Aldridge and Brigham, various other authors have criticised the rule. For example, Brown et al. (1999) endorsed the idea of replacing it with an index based on more scientific scales considering the weight, buoyancy and volume of the tag in relation to the mass and activity of the wearer. Likewise, Jepsen et al. (2005) critiqued that a ‘credible’ tag-body/mass-ratios recommendation must consider other aspects such as the tag attachment method, in relation to the wearer’s life stage, size, species, sex and habitat. The authors claim that “*it is insufficient to assume that a tag/bm [body mass] ratio is appropriate*” and “*few studies have systematically investigated the effects of different tag/bm ratios, and recommendations on maximum ratios often seem to be unfounded statements*”. Despite these proposals to discard the rule, this is still followed and considered good practice by many. In fact, in a study conducted by Smircich and Kelly (2014) on the safety of the 2% rule in brook trout, the authors suggest that the guideline can be safely extended up to a 7% ratio. In the case of EcoLocate - a network composed of six different weight categories of tags that communicate with each other wirelessly in an open landscape (mentioned in section 2.1.1, p. 17) - the 5% rule is exploited to justify the mounting of heavier tags on big animals (such as elephants or rhinos) so that they can serve as receiving and transmitting stations. As they carry many extra batteries, their function is to carry out most of the transmitting work of the network (Markham and Wilkinson 2008). Although this system enables the use of very light tags on small fauna, this is done to the potential detriment of large animals and in contrast with another guideline which states that, from an individual’s

perspective, a device should be as light as possible (Morton et al. 2003). EcoLocate exemplifies concerns recently expressed by Portugal and White (2018), who conducted a meta-analysis on 48 years of biotelemetry literature about the topic of device miniaturisation. The authors found that, although technology has advanced towards miniature tags, this progress has not translated into a reduction of the rule's 5% value, which could benefit the wearer. On the contrary, technological progress has made possible and incentivised monitoring of ever smaller species, for which the 5% rule has continued to be implemented (Portugal and White 2018).

The inadequacy of the 5% rule can be demonstrated by performing a rough calculation on familiar animals. For example, for a 5-kilogram cat, 5% is equal to 250 grams, comparable to the weight of two smartphones; for a 60-kilogram human, 5% corresponds to 3 kg; and in the case of a 720 kg cow, the device could weigh up to 36 kilograms. Even when the 2% rule is considered, the load is still substantial: 100 g for the cat, 1.2 kg for the human, and 14.4 kg for the cow respectively. It has to be stressed that biotelemetry devices are in many cases (especially in the case of wildlife) constantly fastened to the wearer's body. This is analogous to a human carrying a 1.2-3 kg backpack for months without being able to remove it. The analogy highlights how inadequate the 5% rule is, particularly in its generalised terms, and raises questions such as: would a 36 (or even 14.4) kilogram load on a cow be experienced as snugly and be comfortably borne by *her*? If not, how would one decide what is the actual burden that *she* can comfortably carry?

In contrast to the oversimplification of the 5% (or 2% or 3%) rule, animal welfare researchers such as Morton and colleagues (2003), Hawkins (2004), Wilson and McMahon (2006), and Casper (2009) highlighted the importance, on both welfare and scientific grounds, of considering the needs of individual animals in more detail. With respect to equipment, welfarists have offered a more inclusive set of recommendations, in which they argued that, in addition to mass (which must be kept at a minimum), designers and researchers should carefully consider the physical aspects of shape, material, colour, location and method of attachment in relation to the biological and behavioural characteristics of the animal. Their key considerations are summarised in Table 2.1 and include:

**the shape and orientation** of the device should be such that drag and abrasion on the animal's body are minimised, and that movement and performance of vital functions are not impaired (Morton et al. 2003; Wilson and McMahon 2006; Casper 2009);

**the materials** used for the implementation and attachment of the devices should wherever possible be temporary so that the device does not have to remain attached to the animal longer than necessary (Morton et al. 2003; Casper 2009), and should not lacerate animals' tissues, disrupt thermal mechanisms and waterproofing, or be buoyant (Casper 2009);

**the colour** of the external components including harnesses, cases and markers should ensure that the appearance of the device does not affect the animal's social status or attract the attention of predators, prey or ill-intentioned humans (Morton et al. 2003; Casper 2009), that the device blends in with the animal colour (Wilson and McMahon 2006), and that the dye used is not toxic (Casper 2009);

**the length and size** of the device should be considered in relation to the animal's sleeping habits, to avoid pressure on the bladder, liver or diaphragm whilst in the sleeping position (Morton et al. 2003; Hawkins 2004);

**the position** of the device in relation to the animal's barycentre should be such that it does not compromise their posture and equilibrium (Morton et al. 2003; Casper 2009);

**the method of attachment** should be tailored to the species such that it causes the least discomfort or distress possible (Morton et al. 2003) and it should address the risk of trapping wearers (Casper 2009).

Additionally, these authors provide specific directions as to how their recommendations could be applied in practice in relation to the biological and behavioural requirements of animals involved in biotelemetry studies. For example, they discourage the use of red components (Hawkins 2004), recommend the streamlining of the tag shape following the aero- or hydrodynamic form of the animal (Wilson and McMahon 2006), and advocate the use of biocompatible, non-buoyant, dissolvable or time-releasable materials (Casper 2009).

<b>Physical aspect</b>	<b>Recommendations</b>
Shape / Orientation	Minimise drag Minimise abrasion Not to impair movements Not to impair vital functions
Material	Be temporary Not to lacerate tissues Not to disrupt thermal and waterproofing Not to be buoyant
Colour	Not to affect animals' social status Not to attract attention of predators, prey or ill-intentioned humans Be blend in with animal coat Not to use toxic dye
Length / Size	Consider animal's sleeping habits Avoid pressure on internal organs
Position	Consider the animal barycentre to not compromise equilibrium
Method of attachment	Tailored to the species to not cause discomfort Avoid the risk of trapping animals

*Table 2.1: Key recommendations of welfarists regarding the physical aspects of devices.*



### 2.3.2 Critical assessment of the guideline approach

Although less commonly cited and more broadly interpreted than the 5% rule, the above design recommendations are a valuable and useful asset for designing devices that impinge less. When applied, they could help designers consider animal-oriented aspects other than just size and weight, leading to the design of devices that have wearer-centred properties.

However, such recommendations still present a number of limitations:

Firstly, due to the fragmentation of this research area, they are scattered across different sources within different domains (e.g. ecology and animal welfare), so designers seeking to follow best practice have to search far and wide. This is time-consuming and there is a risk that they may miss relevant design recommendations. Moreover, for some of these recommendations, there is no agreement within the biotelemetry community, or they appear to contradict each other; the case of the 5% rule being the most prominent example. It follows that the application of such guidelines is limited and inconsistent, in other words, *unsystematic*.

Secondly, these guidelines advocate designing devices that are consistent with the wearers' physical and lifestyle characteristics (for example, shaping the device according to the hydrodynamic silhouette of aquatic animals (Wilson and McMahon 2006; Casper 2009)) to ensure that the needs of the wearers are taken into account; however, their proponents do not offer general directions as to how designers could *systematically* identify the needs of the wearers and take them into account within a principled design approach.

Thirdly, these guidelines often lack the animal perspective they aim to support. For example, as mentioned above, in one of their recommendations, the proponents discourage the use of the red hue in device components, suggesting that this particular colour can be interpreted as blood by predators or conspecifics (Hawkins 2004). Indeed, this may be the case if said predators or conspecifics are able to see colours in the same way that humans do, and more importantly, if they use sight as the guiding sense towards blood, and colour as the characterising feature of blood. However, many mammal species have di-chromatic vision (Jacobs 2009) and many such predators are attracted towards prey by scent rather than sight. For example, wolves have a highly sophisticated olfactory system, which they use to track prey (Conover 2007), but a scarce ability to detect red objects, perceiving them in shades of grey instead. Although a red harness or tag encase might generate an impact (for example, by disrupting the camouflage of a wearer, or being seen by creatures that discern a wider gamut of colours – e.g. birds), generally speaking design recommendations should be informed by criteria that *systematically* extend beyond the human perspective (which associates the colour red with blood and colour as a salient marker of blood).

These limitations highlight the need to improve on current guidelines approach so that they are easy to access and consult, support a methodical approach, and are consistent with the

animals' perspective when informing directions. But how might these improvements be achieved?

To answer this question, approaches from the design domain were considered. Firstly, the use of biotelemetry guidelines, with its limitations, is exactly the kind of checklist approach criticised by Blackwell and Green (2003), as discussed in section 1.3. Blackwell and Green's aim is to facilitate integrative and systematic approaches in technology design. To this end, they propose to employ design frameworks instead of guidelines. Indeed, developing a comprehensive design framework to inform the design of biotelemetry devices might provide much needed systematicity to current design approaches, which are based on guidelines. This view concords with Gould and Lewis (1985) who refers to guidelines as "*an informal collection of suggestions, rather than as distilled science*", as they are not flexible enough to account for contextual variations, on which design is highly dependent, and are often informed by personal sensitivity and knowledge rather than established principles or empirical data. For example, a guideline that stated that a device must not add buoyancy to the body of fish, might not help designers realise that buoyancy affects diving birds too.

Secondly, the guidelines proposed by welfarists clearly consider *animals' needs, characteristics, and environments*. In fact, habits (e.g. sleeping positions), physicality (e.g. barycentre), living mediums (e.g. water), interactions (e.g. with predators), or physiology (e.g. thermal mechanisms) are variables that should determine the properties of device features such as shape, material, colour, length, etc. The centrality given to the animals is analogous to the *early focus on users* that characterises design philosophies such as User-Centred Design (UCD), according to which a technology should be shaped *around* its users (Gould and Lewis 1985)<sup>9</sup>. As an illustrative parallelism, the UCD approach might inform the design of an underwater computer for scuba divers (e.g. a SeaSlate from WetPC's<sup>10</sup>) by adapting it to the divers' requirements dictated by their characteristics (typically, divers have only one hand free while moving), activities and environments (e.g. operating a keypad while swimming, searching areas on the sea bottom). Similarly, welfarists' guidelines might inform the design of an underwater device to monitor seals according to requirements dictated by their characteristics (e.g. seals have a tapered silhouette adapted to the water medium), activities and environments (e.g. swimming to catch penguins for food). In other words, current guidelines for the design of biotelemetry recognise the centrality of wearer stakeholders within the design process, as UCD does for user stakeholders. This is a

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<sup>9</sup> The early focus on users and tasks, together with empirical measurement and iterative design, are three tenets of design formulated by Gould & Lewis (1985) to designing for usability. They have become widely accepted as the basis of UCD (e.g. Mao et al. (2005) use them for articulating a definition of UCD in their survey). In this dissertation, the early focus on users is broadly considered as a value to achieve as much as possible an understanding of wearers, in order to design 'around' their characteristics, activities and environments, though some techniques advised by Gould and Lewis (i.e. interviews and discussions) are not usable with animals.

<sup>10</sup> <http://www.wetpc.com.au/seaslate> (accessed 30 January 2019).

fundamental alignment of values and philosophy, suggesting that making reference to UCD could help develop a systematic approach to designing animal-centred biotelemetry.

In fact, UCD has already directly informed the fundamental values underpinning the discipline of Animal-Computer Interaction (ACI), informing a range of animal-centred approaches to the design of technology intended for animals (Resner 2001; Mancini et al. 2013; Mancini et al. 2017; Zamansky et al. 2017). Hence, this research positions itself within the ACI landscape and, consistent with its animal-centred values and approaches, contributes to its further development by adapting UCD to systematically account for the requirements of animal wearer stakeholders.

The next section elucidates the relation between ACI and UCD to articulate why this research is framed within ACI. Then, section 2.3.4 discusses the relation between the concepts of active users and passive wearers, and the extent to which UCD tenets and frameworks are useful, or need to be adapted, when designing wearer-centred biotelemetry.

### **2.3.3 Design approach in ACI**

In recent years, the emerging field of Animal-Computer Interaction has laid the foundations for a shift in perspective in the humanistic domain of computing. The relatively young ACI discipline (Mancini 2011) makes reference to Human-Computer Interaction (HCI); yet, it crosses HCI boundaries by recognising individuals of non-human species as users of technologies (Mancini et al. 2014; Mancini et al. 2017). As a consequence, ACI researchers (in particular, Resner (2001) and Mancini (2013)) have proposed UCD as a design approach for animal-centred technologies, subscribing to its philosophy that the development of an interactive product should be driven by users' characteristics (which in ACI are animals), their activities and environments, and when possible, with their direct involvement. In this respect, ACI researchers refer to key values, such as *focussing on users* (Gould and Lewis 1985; Gulliksen et al. 2003), to place the animal user at the centre of the design process and investigate ways of representing their perspective within it. Hence, ACI researchers have applied UCD tenets and adapted Interaction Design (ID) methodologies to develop technology *for* animals, consistent with their characteristics (Mancini et al. 2017). Typically, these are technologies that animals are expected to *use*, often to facilitate tasks they already perform, as in the case of assistance dogs who are trained to interact with human interfaces, such as light switches, washing machines and other appliances<sup>11</sup>, to support their physically impaired human handlers. From a user-centred perspective, if dogs have to operate such appliances, these should afford them good usability<sup>12</sup> and, more comprehensively, a good *user experience* (UX)<sup>13</sup>. In this respect, dog's UX (which encompasses usability – e.g.

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<sup>11</sup> See Assistance Dog International website (<https://assistancedogsinternational.org>).

<sup>12</sup> Usability is described as “*The extent to which a product can be used by specified users to achieve specified goals, with effectiveness, efficiency, and satisfaction in a specified context of use*” by the ISO 9421-11 ([www.https://www.iso.org/obp/ui/#iso:std:iso:ts:20282:-2:ed-2:v1:en](https://www.iso.org/obp/ui/#iso:std:iso:ts:20282:-2:ed-2:v1:en)).

<sup>13</sup> User Experience is defined as “*how [users] feel about a product and their pleasure and satisfaction when using it*” by Preece et al. (2005, p. 12).

enabling the dog to understand how to use the system and when *he* has interacted successfully with it (Robinson et al. 2014) - and experiential aspects – e.g. ensuring that the interaction is a positive one) should be designed considering the physical, psychological and behavioural characteristics of the canine users, in order to appropriately support their work and welfare.

In order to design from a user-centred perspective, UCD and ACI researchers alike recognise the importance of involving users in the design process. For example, when designing a canine alarm system to enable medical alert dogs to call for help on behalf of their incapacitated human handlers, Robinson and colleagues explored the interaction of dogs with the device and tested with them a tug-and-pull mechanism for activating the interface, in order to investigate its affordance for a canine user (Robinson et al. 2014). This case provides an example of how animals' characteristics, and their preferences identified through their involvement in the design process, can inform the design of animal-centred interactive products, whereby "*real users and their goals, not just technology, are the driving force behind product development*" (Preece et al. 2015, p. 327).

So far, most of ACI research has applied an UCD approach to designing interactive systems that animal users actively and cognitively operate, such as technological games for pets (Westerlaken and Gualeni 2014), enrichment products for zoo animals (French et al. 2017), touchscreen interfaces for dogs (Zeagler et al. 2014), alarm systems for assistance dogs (Robinson et al. 2014), tug and bite wearable sensors for search and rescue dogs (Jackson et al. 2015), or wireless home switches (Mancini et al. 2016). However, when it comes to animal biotelemetry, typically animals do not operate the devices they carry, therefore aspects of UCD that specifically relate to user's goals and tasks<sup>14</sup> do not seemingly apply when designing biotelemetry under the (animal) wearer's perspective. Nevertheless, there is undoubtedly a bodily interaction between animal-borne tags and animal wearers, which potentially generates impacts, and therefore a negative *wearer experience (WX)* that needs to be understood in order to designing animal-centred biotelemetry that do not impinge on them. In this research, by WX it is meant how animals sensorially, physically, and cognitively perceive a tag attached on their bodies in relation to the potential impact generated by their bodily interaction with it.

Such detrimental interaction identifies animal biotelemetry as an area of interest for ACI, since this thesis's ultimate objective is to foster the improvement of a WX, in accordance with the ACI's aim of improving the life of animals involved with technologies (Mancini 2011). Thus, this work is framed within the ACI design approach (which mostly employs UCD values and frameworks for the design of technologies for animals), and it contributes to the discipline by adapting UCD to the design of biotelemetry, where animals do not

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<sup>14</sup> Users' goals and tasks are strictly connected with usability, since if a product lacks usability, users may struggle in reaching their goals and have an unsatisfactory experience.

actively operate a device but still experience an interaction with it, as discussed in the next section.

#### **2.3.4 Interactors in animal biotelemetry: Human users and animal wearers**

Typically, with human biotelemetry, the wearer of a device is also its end user and voluntary consumer (e.g. a runner who tracks the covered distance and route with a GPS system for personal training purposes). However, with animal biotelemetry, there is a user/wearer dichotomy: while humans are the remote *users* who put tags on animals, are interested in gathering biological data from fauna, and actively interact with the user interface in order to operate and retrieve data from the devices, animals are the physical *wearers* who are coerced to carry tags and are neither aware or interested in monitoring and collecting data on their activity. Nevertheless, they have a bodily interaction with the tag they wear, which involves their sensory and physical apparatuses, and from which they cannot withdraw. Hence, human operators and animal carriers are two different stakeholders and distinctive kinds of *interactor* (North 2016) of wearable technology.

The interaction that comes from using or wearing a tag is different. The (human) user-tag *interaction* can be defined as a feedback loop between user and machine, in which the person achieves a goal by giving an input to a system that responds by giving an output. Such response is then interpreted by the user which decides whether their goal is achieved (Dubberly et al. 2009). This is an active, intentional and purposeful interaction. To some extent, this model still applies to animal users and interactive devices they operate, although it is acknowledged that the nature of animals' goals and intentions when interacting with devices is unknown. What is important here is that users, no matter whether animals or humans, have some goal for using a technology, while animal wearers of biotelemetry do not. The (animal) wearer-tag interaction is not active, intentional or purposeful, assuming that animals do not recognise human-made abstract objects such as data and, anyway, from their perspective, they do not gain any 'everyday' benefit from monitoring nor do they have a choice as to whether to wear a tag or not.

However, in spite of these critical differences, UCD's approach to designing interactive systems is still relevant to this research. As discussed in section 2.3.2 (pp. 29-30), for both UCD and existing biotelemetry guidelines the focus of the design process is the interactor (users, on the one hand, and wearers, on the other hand). This convergence provides a basis from which to explore the adaptability of UCD and its core values to the design of bodily interactions, regardless of the fact that these interactions are not active and thus design principles pertaining to user goals and tasks are not directly relevant. At the same time, exploring the possibility for such adaptation has the potential to expand UCD to include interactors other than users, enriching the variety of interactors and interactions that can be accounted for within such an approach. Hence, questions arise as to:

1) how, and to what extent, UCD might be applicable in a context in which animals are wearers but not users<sup>15</sup>; 2) how wearers' needs might be represented in the design process when the type of interaction traditionally accounted for by UCD is so distinctly different from the one experienced by (animal) wearers. The bodily interaction accounted for here relates to the concept of *wearability* in wearable design, which becomes central to this research and will be addressed in the next section.

## **2.4 The concept of wearability and wearable design**

Section 2.3.3 discussed how providing good usability and good UX is a main goal of user-centred technology. The fundamental assumption is that the technology the user interacts with is directly relevant to them and their activities, which is the theoretical basis of UCD, whether applied to humans (Gould and Lewis 1985) or animals (Mancini 2013).

In UCD, interactions between users and machines are systematically informed by established *design principles* (e.g. perceivability, affordance, feedback) which guide developers to design for good usability and good UX (Preece et al. 2015, p. 25). However, as discussed above, in the case of animal biotelemetry, wearers physically interact with a technology that does not serve their own purposes but those of someone else. Hence, the question arises as to what might be the equivalent of a 'good experience' for biotelemetry wearers. In this case, the usability goals (e.g. learnability, memorability) and principles that inform user-centred design (e.g. feedback and affordance) do not seem relevant for addressing the impacts that derive from the interaction between the animal's body and the worn device, and which determine animals' experiences (i.e. WX) with a tag.

To account for the experience of wearer interactors, we argue that there is the need for a complementary framework in biotelemetry design that focuses on 'wearers' instead of 'users' requirements, and that comprises 'wearability' instead of 'usability' goals and principles.

Not surprisingly, wearability is a design goal that has been considered by HCI researchers following the advent of wearable computers (Knight et al. 2006). Also, HCI researchers have pioneered some work related to it (Valentin et al. 2015a). In order to clarify the extent to which wearability operates in the design of biotelemetry devices, approaches for addressing both human and animal wearability are described more in detail in the next two sections (2.4.1 and 2.4.2 respectively).

### **2.4.1 Wearability for humans**

In this thesis, animal biotelemetry tags are referred to as a kind of *wearable computer*. With respect to what has been said in section 2.3.4, human biotelemetry devices certainly are. In

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<sup>15</sup> The stance in this research is that UCD can be applied when the designer has an interest in fulfilling the interactors' needs. Although other interpretations might be considered (e.g. that animal wearers are passive users and they come under a broader definition of user), this research uses the umbrella term of interactors, while distinguishing such interactors on the basis of their interaction with the device.

fact, the definitions of wearable electronics available in the literature within the domain of human wearable computing regard interactors as simultaneously users and wearers. For example, Knight and colleagues define a wearable as a computer that “*is attached to the body and does not require muscular effort to remain in contact with the body (i.e. you do not have to hold it, which would require muscular grip force); (...) remains attached to the body regardless of the body’s orientation or activity (i.e. you do not have to take it off to perform a task specific action, even when not using the computer); (...) does not have to be detached to be interacted with*” (Knight et al. 2006, p. 75). At the same time, however, the fundamental characteristic of a wearable expressed in such definitions is its close relationship with the body, which highlights the role of physical aspects as central in relation to the interaction.

As such, wearability concepts have been proposed exactly to interpret such bodily relations. Early proposals are from the early ‘80s, when Steve Mann pioneered the practice of devising, crafting and using his own body-borne computers and sensors (Mann 1996). Mann tells an early story of physical and social awkwardness due to the conspicuousness of the system he wore, where people around him conveyed astonishment about the cumbersome combination of body and machines. However, Mann’s goals were about functionality and capability rather than unobtrusiveness, such that he reported feeling more empowered than uncomfortable with his garish equipment and carried on wearing it in communal spaces such as banks. What Mann himself pointed out in his narrative, and which has importance for this research, is that wearables have a “*very intimate form of interaction with the wearer*” and such interaction might either violate the personal space (e.g. the interactor does not accept the device) or provide exceptional control over the wearer’s activities (e.g. the interactor feels enabled with extra capabilities) (Mann 1996). Ever since, in order to minimise obtrusion (which relates to physicality) and maximise control (which relates to usage), wearable devices have progressed to combine functionalities and capabilities with miniaturisation, leading to a much wider acceptance, normalisation and consumption of wearable devices by the public compared with Mann’s early developments.

Later on, Gemperle and colleagues named the physical properties of wearables ‘wearability’ and defined this as “*the interaction between the human body and the wearable object*” (Gemperle et al. 1998). Moving beyond the simple miniaturisation of wearable devices, the authors referred to the human body as the dynamic and sensory environment that supports the wearable. Consequently, the wearer’s body shape, motion, and sensory apparatus should determine form, location, and attachment features of the device. In this sense, wearability becomes the goal of shaping the physical features of a device in a way that conforms with an acceptable mobile and sensory interaction. In their study, the authors proposed 13 guidelines for accomplishing wearability based on the human form and dynamics (Gemperle et al. 1998). They are:

- 1- *Placement*: where the wearable should be placed on the human body in order to be **unobtrusive**.
- 2- *Humanistic form language*: what human body curves (concavities and convexities) the wearable should reflect in order to be **comfortable**.
- 3- *Human movement*: how joints and muscle contractions limit the positioning of a wearable to allow **freedom of motion**, while shaping the form of the wearable itself.
- 4- *Proxemics*: to what extent the wearable can **protrude** from the body without hitting against surfaces, so it is not perceived as foreign to the intimate space around the body.
- 5- *Size variation*: how a wearable can **adjust** to changes in muscle and fat mass.
- 6- *Attachment*: how a wearable can be fastened to the body in a **comfortable** and **adjustable** way.
- 7- *Containment*: in what way the form of the electronic components inside a wearable **constrain** the shape of the external case.
- 8- *Weight*: where to put a wearable without destabilising the **balance** of the body.
- 9- *Accessibility*: how to make a wearable more **usable** through **sensory inputs** (through the wearer's body) such as visual, auditory, and tactile stimuli.
- 10- *Sensory interaction*: how something that is on the body is **perceived**.
- 11- *Thermal*: how a wearable affects the **body's need** to breath and its sensitivity to the heat that the wearable may produce.
- 12- *Aesthetics*: what shapes, materials, textures and colours are **preferred** by users.
- 13- *Long-term use*: what are the physical and mental effects that may be produced by a device that is **continuously attached** to the human body (which implies that wearing a device is somewhat equivalent to using it).

Most of these guidelines (namely placement, form language, movement, proxemics, sizing, attachment, containment, weight, thermal, aesthetics, and long-term use) could be applied to the design of animal wearables, consistently with the animals' characteristics. For example, the suggestion of considering joint and muscle contraction for designing a wearable that allows freedom of motion on the site of attachment is applicable to any animal (human or non-human) and would need to take into account the joint and muscle qualities of the target species.

However, these guidelines also consider aspects of the design that are not relevant to the design of animal biotelemetry. For example, *accessibility* does not apply in the case of animal wearers, since they are not users; and since they are not users, *sensory inputs* (i.e.



sensory stimuli) are not required and are, in fact, undesirable. Indeed, if animal wearers are not trained to use a device, any *sensory interaction* is foreign and therefore liable to produce an effect (for example, an electronic sound coming from a body-attached tag might mystify the wearer about its origin). Then arguably, the device should produce no stimuli for the wearer, that is it should be imperceptible, in order to avoid interference with the wearer's daily activities and experiences.

Overall, these guidelines provide a good basis from which to start designing wearables for animals, taking into account the target species-specific sensory, physical and cognitive characteristics, consistent with the existing guidelines for animal biotelemetry described in section 2.3.1. Indeed, merging human-centred and animal-minded guidelines is the approach currently taken by ACI designers such as Valentin and colleagues (Valentin et al. 2015a). (The authors' work and its limitations will be more extensively described in the next section 2.4.2, dedicated to animal wearability). However, as discussed in section 2.3.2 (p. 28), a guideline approach is limited with respect to a framework, since it does not foster the exploration of other variables and contexts other than those prescribed by the guidelines themselves, and since it is vulnerable to subjective thinking rather than facilitate systematic reasoning informed by established principles (Gould and Lewis 1985; Blackwell and Green 2003).

A different approach to human wearability is that of Anliker and colleagues (2004), who proposed a systematic methodology for the design of wearability in human wearable systems, which integrates functionality and hardware aspects. Particularly with regards to the hardware properties, the authors explicitly refer to wearability as a design goal and state that "*the wearable system needs to be unobtrusive to the degree that it does not interfere with the user's activity and does not change his appearance in any unacceptable way*" (Anliker et al. 2004). In this respect, they refer to wearability as a physical constraint and developed a metric to calculate a *wearability factor* with which to determine how obtrusive a device might be for a human wearer. The tool that they provide is a generic flexible formula whose terms have to be determined case by case. In other words, in order to calculate the wearability factor, other parameters and values are needed to replace the generic formula terms. Relevant parameters include size, mass, or heat dissipation. However, Anliker and colleagues do not discuss them further; instead, the authors delegate the decision as to which aspects need to be considered and quantified to research fields such as ergonomics and sociology (Anliker et al. 2004).

This kind of quantification still is missing in animal biotelemetry, rendering the Anliker's tool inapplicable with animals. At present, there is little prior quantitative work specifically focussing on animal wearability factors. What work is there refers to aspects related to animal usability of wearables when animals are concurrently wearers and users, thus intertwining wearability and usability aspects of a design, as in (most of) human

biotelemetry (e.g. trained search and rescue dogs who wear vests allowing them to remotely communicate with their handlers through a wearable interface). So far, snout reachability in dogs has been investigated by Valentin and colleagues at Georgia Tech's ACI Lab (Valentin et al. 2014) to establish the twisting capabilities of canine trunks and which part of their body dogs can access more easily with their nose, and thus where to place a wearable interface for the dog to use to complete given tasks. In this case, 'reachability' is accountable as a usability-wearability factor; however, this factor loses its relevance when animals are only wearers.

Although both Anliker (2004) and Valentin (2014)'s work provides a solid basis on which to build a systematic approach to wearability design for animal wearables, Anliker's proposed framework is not detailed enough and not applicable given current animal wearability knowledge, while Valentin's detailed model is relevant to wearability only when this is linked to usability. Hence, there is a need for a comprehensive but more detailed framework that is specifically focused on aspects that directly pertain to wearability (i.e. the very fact of wearing a device). Next, section reviews some of the work that has such a focus on animals.

#### **2.4.2 Wearability for animals**

The same authors who investigated on-body interface reachability in dogs (Valentin et al. 2014) also researched animal wearability as a design goal for animal wearables at the level of the physical interaction with the worn device, pioneering a requirements analysis in this respect. In particular, Valentin and colleagues (2015a) analysed the wearability challenges presented by electronically enhanced collars and harnesses used on working dogs, highlighting safety, space, comfort, and weight as important aspects for improving wearability (Valentin et al. 2015a). Learning from their previous design experience with dogs (Jackson et al. 2015; Valentin et al. 2015b), the authors proposed a series of recommendations for neck-worn and trunk-worn devices, such as:

- keeping the projection of the device as low as possible to minimise the risk of the wearer being caught or bumping against surfaces;
- using break-away mechanisms that release collars or harnesses if trapped;
- leaving free areas on the wearables on which the animal can comfortably lie when resting;
- opting for instrumentation weight of less than 2% of the animals' body weight;
- recommending that hair should not be caught in and pulled by components and attachments (such as buckles or electronic modules), and that the inner side of the wearable should be soft and seamless.

At a glance, it is clear the similarity with the following biotelemetry recommendations and Gemperle's guidelines. For example (see section 2.3.1 for parallel comparison):

the requirement to keep the projection low to prevent wearer from getting caught or to use break-away mechanisms if the wearer does get caught address a concern expressed by welfarist Casper (2009); the requirement to keep projection low to avoid bumping on surfaces relates to Gemperle's proxemics parameter (to which the authors make direct reference);

the requirement to leave free areas on the wearable to allow the dog to comfortably lie when resting is consistent with the aspect of comfortability in Gemperle's work and with welfarists Morton et al. (2003) and Hawkins (2004)'s advice to bear in mind resting habits to avoid pressure from the device on tissues and organs;

the 2% rule is directly invoked (with reference to an earlier design paper that devised a cat-borne camera (Yonezawa et al. 2009)).

Whilst Valentin et al. (2015a)'s guidelines are broadly aligned with existing welfarists' guidelines for the design of biotelemetry, there is no open reference to these. As the authors state, their own guidelines are derived from their extensive empirical knowledge and handling experience with the dogs, and from a sensitivity developed through years of training and working with them. However, not everyone who develops biotelemetry device might have the same computing and design skills, coupled with the same level of empirical knowledge and experience about their target species.

Moreover, the aspects empirically identified by Valentin et al. (2015a) as relevant in the design of the wearable are limited to a few (i.e. size, weight, projection, some reference to texture) in comparison with the many that could cause discomfort and obstruction for an animal wearer (e.g. colour, material, texture, length, orientation of the tag, as reported in section 2.3.1).

This highlights how the lack of a systematic approach to the identification of wearability requirements may fail to account for many important variables that are relevant to wearable design. In accordance with Blackwell and Green (2003), had the authors had at their disposal a framework to inform their reflection on wearability, they might have been able to identify a more comprehensive set of design variables.

In summary, Valentin et al. (2015a)'s work is symptomatic of the main limitations that characterise current approaches to biotelemetry design, as discussed in section 2.3.2 (p. 28): existing guidelines concerning wearability (Morton et al. 2003; Hawkins 2004; Wilson and McMahon 2006; Casper 2009; and Gemperle et al. 1998) are dispersed across different domains and hard to find (first limitation), without a reference framework they cannot support the systematic identification of design requirements (second limitation), and they

are limited in representing the animal perspective (third limitation). Consequently, so far, the success with which designers have identified and engaged with suitable resources has often been down to the sensitivity of individuals to the design problem. In turn, this sensitivity is often reliant on said individuals having a sufficiently interdisciplinary background. This may easily result in an approach to the design of biotelemetry interventions that does not account for as many variables as possible in relation to as many requirements as possible in a systematic and balanced fashion. This is particularly the case when researchers and designers wish to design interventions for species that have not yet been studied or that have been minimally studied, for which not many cases are available that could be referred to. All these considerations suggest that a dedicated and systematic wearer-centred approach to the design of animal biotelemetry is needed and could play a beneficial role in the design of biotelemetry devices, shifting the perspective towards animal wearers' needs instead of human users' usage. To date, there is no comprehensive wearer-centred framework that can systematically account for existing guidelines, and that can be applied to animal species.

In other words, despite the fact that there is growing consideration for the wearer as a stakeholder in the design and development of wearable biotelemetry for animals, the design of biotelemetry products is still mostly dependent on the sensitivity and background of the designer. This highlights the need for design frameworks that could help designers systematically account for the variables that are relevant to the biology and ecology of the wearers' specific characteristics, according to appropriate design principles. In this research, it is envisaged that the development of such an instrument could be a first step towards the development of a wearer-centred approach, analogous and consistent with the user-centred approach.

## **2.5 Conclusions of the literature review: Designing for wearability**

This literature review provides an overview of what biotelemetry is (2.1), how wearing biotelemetry devices impacts animal wearers (2.2), and what guidelines are currently adopted to design tags that impinge less on animal welfare (2.3). In particular, the review identifies the key problems of how to design in a way that is consistent with the animals' perspective, and how to enable designers to systematically account for the wearer's requirements during the design process. These issues highlight a need for an analytical instrument, which suitably integrates insights and design guidelines from ecologists and animal welfare experts with frameworks and approaches typically used in UCD. Although designers have started to recognise wearability as a goal, it is clear how an approach that effectively takes into account the wearer's perspective, and an instrument that enables designers to systematically take the wearer's perspective, are still lacking (2.4).

In this respect, the development of a wearer-centred framework for the design of biotelemetry wearables could enable designers to *systematically* establish requirements for

the design of biotelemetry systems that are consistent with the perspective of the species being instrumented, thus leading to both better data and better animal welfare.

In a nutshell, this research proposes to apply the design philosophy of UCD, from which the use of frameworks has been borrowed, and to extend UCD's focus on the user to include, and account systematically for, wearer interactors and for physical interaction. This is in accordance with ACI's fundamental focus on animals when designing technologies used by or on them, regardless of whether they are active users or passive wearers. Thus, this work directly contributes to the development, and extends the remit, of ACI. Ultimately, this research is envisaged as the first step towards integrating a wearer-centred perspective with the user-centred approach already adopted in ACI and generate an animal-centred approach that goes beyond the nature of the interactions in question, and that applies whether interactors are users or wearers, while accounting for the peculiar needs of animals as primary stakeholders of technologies that can affect their welfare.

### **3. RESEARCH METHODOLOGY: Methods for developing, applying and evaluating a wearer-centred framework for animal biotelemetry**

This chapter accounts for the methodological approach undertaken within this research to develop, apply and evaluate a first version of the Wearer-Centred Framework (WCF). The literature review in chapter 2 discussed the problem of device-induced impacts on animal wearers, the limitations of a guideline-based approach to designing tags that impinge less, and the very limited existing work on the investigation of wearability for animals. Although some work addressing wearability exists (for example, Valentin et al. (2015a)), different guideline sources are heterogeneous and dispersed, leading to a lack of systematisation in identifying animal wearer's needs during the design process of biotelemetry technology. This research proposes to address these problems by developing the aforementioned WCF as an instrument for informing the design of animal-borne tags that provide good wearability, with the underlying aim of improving the wearers' experience (WX).

This chapter contains an overview on how this research was conducted in relation to the three operative questions expressed in section 1.2. Also, it motivates the methodological approach and the epistemology at its base (3.1.1) and presents the animal species chosen for a pilot application and evaluation of the WCF (3.1.2). Then, it provides detailed descriptions of the data collection methods employed (3.2), of the prototyping stage (3.3), of the data analysis methods (3.4), and a summary of the research ethics procedure (3.5).

#### **3.1 Overview of the research**

This research focuses on addressing the problem of biotelemetry-induced impacts on animal wearers. In order to do so, it proposes to design for wearability by employing a framework that guides developers towards a wearer-centred design. In this respect, the WCF is intended as a *'proxy'* tool whose purpose is to remind designers that animal wearers are primary stakeholders and that biotelemetry tags must be devised 'around' them during the design process. Hence, the objectives of this research were to generate the WCF, to apply it as a part of the design process, and to evaluate its usefulness for designers and its suitability for reducing impacts.

Developing, applying, and evaluating the WCF was achieved through a three-phase research project in which each phase aimed to answer a specific question, each requiring the collection of a specific type of data in order to address it. Types of data, their sources and methods for data collection, as well as the methods for analysing them, are illustrated in Figure 3.1 and are outlined with respect to the three questions as follow:

Phase / Purpose		Data Collected	Type of Data	Source of Data	Data Collection Method	Data Analysis Method		
Phase 1: Developing the WCF		Guidelines/recommend. Impacts Animal's needs, characteristics, activities, environments	QUAL	Publications in the literature	Literature review (QUAL)	Document analysis		
Phase 2: Applying the WCF		Workshop requirements	QUAL	Designer's dialogues and actions	Collaborative requirements workshops (QUAL)	Requirements analysis	PROTOTYPE	
Phase 3: Evaluating the WCF	Useful-ness	Dialogues referring to WCF	QUAL			Animal's reactions to off-the-shelf devices		Ethological observations in wearability studies 1 and 2 (QUAL + QUANT)
		Episodes of explicit interaction: study 1 requirements		Critical incident technique				
		Behavioural indicators	QUANT	Animal's reactions to prototype	All-occurrences sampling, Statistical analysis			
		Counting of yes/no occurrence			One-zero sampling			

Figure 3.1: Data collected and their sources, methods for data collection, and methods of analysis in respect to the three phases of the research.

Operative Question 1 (*What elements might constitute such a wearer-centred framework?*) was addressed through an analytical approach. A first version of the WCF was derived by searching information in the literature and by qualitatively analysing it. The process started with the review of published biotelemetry documents, from which data in the form of text describing guidelines, impacts, and animals' needs, characteristics, activities, and environments were selected and interpreted for deducing the elements of the framework. The content of the publications was analysed by adopting a scheme that categorised the information in general principles and criteria following a document analysis approach (Bowen 2009). This scheme adopted the model described for approaching usability and user experience by Preece et al. (2015, pp. 19-30), but it focused on wearability and wearer experience (instead of usability and user experience). In this phase, the role of the researcher was central, in the sense that she relied on her thinking to locate, review and reflect on relevant material. The criteria applied in the process are detailed in chapter 4.

Operative Question 2 (*How could the framework be applied during the design process?*) was an explorative inquiry conducted through a design approach. The objective here was to use the WCF as a facilitating instrument for a systematic requirements analysis, which is one of the basic activities of the iterative design process of Interaction Design (Preece et al. 2015, p. 15). In practice, the WCF was administered to three teams of designers who performed prototyping activities aiming at establishing wearability requirements consistent with animal's characteristics and needs. Designer participants were effectively the executors of this step, while the WCF was effectively the motor. Thus, collaborative methods in the form of prototyping workshops were employed following a focus group data gathering approach (Gottesdiener 2003). The outcomes of this collaborative process were requirements established heuristically that, subsequently to the workshops, served to

prototype a first wearer-centred artefact. This second step (prototyping stage) was performed by the researcher. The workshop activities, outcomes and prototyping stage are reported in chapters 6 and 7.

Operative Question 3 (*How could the usefulness of the framework as a design-informing tool for wearability be evaluated?*) was a double evaluative inquiry conducted in part analytically - through the thematic analysis of what the designers said during the workshops - and in part experimentally - through two observational studies with animal participants (study 1 and 2). More specifically, in addition to the requirements analysis (chapter 6), a qualitative thematic analysis (Braun and Clarke 2006) was conducted of the designers' dialogues recorded during the workshops, through which both direct and indirect references to the WCF were extrapolated to assess *the extent* to which the designers made use of, and were engaged with, the WCF. This served as a direct assessment of usefulness<sup>16</sup>, that is: did the framework help designers to account for animal stakeholders? Did designers apply the principles, values, and concepts provided by the WCF? (chapter 8). On the other hand, the usefulness of the WCF as an instrument to elicit wearability requirements (the extent to which the WCF was appropriate to perform requirements analyses) was evaluated experimentally by means of two observational studies carried out with domestic cats (*Felis catus*) as a model animal species. During the first study (study 1, in: chapter 5), the wearability of two off-the-shelf tracking tags was investigated and wearability requirements were empirically derived. These were then compared to the requirements heuristically established through the application of the WCF during the workshop activities (chapter 6) as a first form of validation of the WCF's usefulness. During the second study (study 2), the wearability of the prototype, which was informed by the WCF, was evaluated with the same group of cats involved in study 1. Behavioural findings from the first and second studies were then put in relation as a second form of validation of the WCF's usefulness (chapter 7). In these studies, cats were involved as design informants and their perspectives were acquired by means of an animal behavioural method called *ethological observations* (Dawkins 2007). Such observations are flexible interpretative tools based on quantitative and qualitative data collection and analysis that allow researchers to both measure and explore animal behaviour within an experimental research methodology.

This is multidisciplinary research which required a mixed-method approach to collect and analyse a variety of data needed to carry out design activities and tool evaluations, typical of computing disciplines, and interpretations of animal behaviours, typical of ethology. The reason why a mixed-method approach was deemed appropriate for this research is motivated next.

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<sup>16</sup> In Interaction Design, *usefulness* is a concept that expresses the achievement of a particular objective (<https://www.interaction-design.org/literature/topics/usefulness>). Our objective here was to assess whether the WCF produces an animal-centred design. Hence, we aimed at answering the question whether designers did account for animal stakeholders and did apply the principles, values and concepts provided by the WCF.



### **3.1.1 Pragmatism and mixed-method approach**

This thesis is motivated by the welfare and scientific problem of device-induced impacts. It addresses the research question of how to design for wearability, to obtain devices that impinge less compared to the ones that can be developed by following current guideline-based design approach.

The focus of the thesis is on addressing the problem of biotelemetry impacts to search for practical solutions. According to Creswell (2014), pragmatists investigate phenomena in order to propose solutions for problems that have been investigated. Thus, pragmatists draw liberally from a range of qualitative and quantitative approaches to best understand a research problem without committing with any particular worldview (Creswell 2014, p. 11).

A mixed-method approach allows the acquisition of a range of heterogeneous data from which to extract information that can best serve the purpose of finding practical solutions to a problem. Analogously, this work aimed at proposing a design framework to address the problem of how to design for wearability. Studies such as analysing design guidelines, investigating experimentally the bodily experience of animals with wearables, and understanding the use that designers made of the proposed WCF were conducted to understand a wide range of wearability issues (e.g. welfarists' stance, animals' experience, and designers' application, respectively) with the final aim of designing for wearability.

### **3.1.2 Focusing on a species**

Although the proposed WCF is intended for application with any animal species, domestic cats (sp. *Felis catus*) were chosen as model species particularly suitable for carrying out wearability tests on biotelemetry devices. This choice had various reasons. Firstly, cats are domesticated animals accustomed to the presence of, and interaction with humans (as opposed to unrestrained wild fauna). This reduces the influence that an observer may have on their daily routine (Martin and Bateson 1993, p. 31) and limits any impact of the research on the animals' welfare. Secondly, cats are popular pets thus widely available in households, which would make it easier to find participants for the study. Thirdly, their behaviour has been extensively studied and a well-documented *ethogram* (i.e. list of behaviours exhibited by a species (Martin and Bateson 1993, p. 41)) is available from which to select behaviours that can be used to measure the animals' reactions to wearing a device (Stanton et al. 2015). Fourthly, cats are a target group for the pet market, which currently offers many wearable devices targeted to them, which in turn makes it possible to evaluate real commercial products and prototypes. Moreover, and importantly for the application of the ethological method, the investigator conducting the observations was very familiar with the species and therefore had knowledge of the cat-specific behavioural repertoire. This is required by the ethological methodology in order to provide an accurate assessment of animal body language (Wemelsfelder 2007).

### **3.2 Data collection methods**

As illustrated by Figure 3.1 (which illustrates the overall mixed-method methodology – in the previous section 3.1), this section presents the methods used for collecting the data for each research question.

#### **3.2.1 Literature review**

Data from which to derive the elements of the WCF were text excerpts, passages and quotations which were selected because they contained information about impacts, guidelines and recommendations, as well as animal's needs, characteristics, activities, and environments as discussed by welfarists and biotelemetrists (reported in section 2.2 and 2.3). We acquired the relevant material by reviewing publications in the literature.

#### **3.2.2 Collaborative requirements workshops**

The WCF was proposed as a tool for facilitating a requirements analysis for wearability. In order to do so, the framework was delivered to teams of designer contributors who participated in three *collaborative requirements workshops* for establishing wearability requirements for a GPS tag consistent with cat's characteristics and needs (details are in section 6.1.3).

Growingly popular among interaction designers (Preece et al. 2015, p. 363), collaborative requirements workshops are variants of the *focus group* technique and are employed as an ad-hoc method for requirements elicitation. As the name 'requirements workshops' indicates, they are specifically tailored to carry out an early requirements activity (Gottesdiener 2003). While focus groups are typically employed to evaluate products that are already on the market, whereby participants are usually asked to express how they use an own device or give their opinions about a product of interest (Cooper et al. 2014, p. 53; Preece et al. 2015, p. 237), requirements workshops are specifically employed to "*quickly elicit, prioritise, and agree on*" a common set of requirements based on which to start a design process (Gottesdiener 2003).

According to Gottesdiener (2003), in order to have a successful requirements activity during a workshop, the following is key:

- 1) The involvement of all representative stakeholders related to the project (i.e. project sponsors, product champions, direct and indirect users, advisors, and suppliers), since they may have different outlooks and needs that may translate into contrasting requirements.
- 2) A careful schedule for the team activities and a structure set up on deliverables that helps the participants to focus on the task.
- 3) A collaborative environment which is conducive to addressing the concerns of all participants.

- 4) The presence of a facilitator who follows the schedule and leads the teamwork. This is necessary both to explain the deliverables and team activities included in the plan and to supervise on the collaborative aspects of the workshop, checking that the participants agree on the requirements, and ensuring that the shiest ideas are given voice.

However, we contravened the first guideline by grouping representatives of the same stakeholder category together, since the objective of our workshops was to evaluate whether the WCF is a useful tool for eliciting wearability rather than carry out a product development. For this, it was more useful to have teams whose members had relatively homogeneous backgrounds, which would allow us to better identify any background-dependent differences in the use and usefulness of the framework, and whether teams having different backgrounds and interests were reaching similar outcomes. Hence, each team was composed by specialists of similar background, interest in technology, and knowledge about the cat species, while across teams there were diversity of such aspects.

In respect to the second, third, and fourth guideline, we adhered more literally to Gottesdiener's model. Thus, in our workshops, we arranged and timed the workshop activities, and administered the WCF as the central deliverable (second guideline); we facilitated a collaborative environment by keeping the number of contributors for each workshop low (four, to be precise) and gathering together people acquainted each other (these were deemed as fair measures to have an equal exchange of opinion among participants and minimise the main drawback of the technique, that is having the loudest participants impose their opinions) (third guideline); we kept the function of the facilitator as proposed by Gottesdiener (fourth guideline) while adding an additional function: the facilitator was also a cat expert who could be consulted whenever the participants had doubts about the biology of the species. Due to this double function, the facilitator trained herself to keep the two roles clear and separate (Preece et al. 2015, p. 255).

The workshops produced a data set in the form of transcripts of dialogues among designers. We firstly read them to derive wearability requirements heuristically (section 6.1.4) that were used to design a prototype during a prototyping stage of the research (section 7.1.2); secondly, we conducted a thematic analysis of the data (described in section 8.2) to evaluate whether the WCF was a useful tool for designers to account for the characteristics and needs of animal stakeholders.

### **3.2.3 Ethological observations in wearability studies**

In order to evaluate the WCF usefulness, the requirements established heuristically through the WCF needed to be validated and improvements of the wearability of the prototype (derived from the use of the WCF) needed to be assessed. This was done by involving animals to establish requirements empirically and to gauge, through their reactions, their experience with devices. Two wearability tests, one with two off-the-shelf GPS tags (study 1) and the other with the prototype derived from the workshop activities (study 2), were

carried out in order to gain insights into the wearability of the different devices from an animal's perspective (details are in sections 5.4 and 5.5 for study 1, and in section 7.2 for study 2).

To investigate the cat participants' WX with the devices we chose to apply an ethological approach. Ethology is a science dedicated to the understanding of animals' behaviour which makes use of repeated *field observation* to characterise and quantify specific behaviours (Tinbergen 1963).

Field observation is a common method for collecting behavioural data both in Human-Computer Interaction (HCI) and Ethology. However, physical, sensory and cognitive interspecies differences between human investigator and animal studied (resulting in differences of perception and communication barriers) underpin key differences in how observation is approached in the two fields. In HCI, direct observation in the field is usually employed as a descriptive qualitative method to understand the details of what users do in naturalistic settings (Preece et al. 2015, pp. 252-254); and usually observational field studies significantly differ from quantitative observation methods applied in laboratory settings, where participants operate under controlled conditions. Either way, a key aspect is that in HCI, observation methods can be complemented by self-reporting methods to somewhat validate observational data. This is of course not possible when working with non-human participants.

In ethology, observation is approached by choosing and defining behavioural categories to observe and quantitatively measure behavioural parameters (e.g. frequency, duration, latency, intensity) in naturalistic settings (Martin and Bateson 1993, pp. 62-66). Observational data are then usually (but not necessarily) treated statistically to verify hypotheses on the meaning of observed behaviours, which thus emerge from quantitative data (e.g. measuring the roaring rate in red deer stags and correlate it with fight occurrences to test whether the roar is an indicator of fitness (Clutton-Brock et al. 1979)). This enables ethologists to interpret the meaning of animal behaviour in a relatively objective way, thus reducing the risk of anthropomorphic interpretations (Martin and Bateson 1993, p. 18; Tinbergen 1963). However, when a single episode of a salient behaviour shows a clear effect, ethologists describe it in a qualitative way. Hence, the observational method adopted by ethologists involves qualitative and quantitative observations in non-manipulative experiments in natural and non-controlled settings (i.e. in the field), in which behaviours of interest are described and measured to test hypotheses on *why* the described behaviours might occur (i.e. exploring their possible meaning). In this regard, salient or unexpected behaviours are annotated and described qualitatively as a basis for prospective measurements, though quantification is performed to achieve as objective as possible an interpretation of animals' behaviour (Dawkins 2007).

A key challenge of interpreting animals' behaviours in the field is that researchers cannot control the environment and actions of the studied individuals as they could in a laboratory setting. Indeed, in the wild, individuals may disappear from the sight of the observer thus interrupting the recording, or they may respond to the observer's presence in a way that invalidates the data (e.g. if they express curiosity, escape or otherwise alter their behaviour); external stimuli such as temperature, light, or interactions with conspecifics are non-controllable variables that may confound the observation of a possible cause-effect relation, and animals are observed as they carry on with their daily routines. These issues are addressed through an observational technique that focuses on a) controlling the observer instead of controlling the animals and their environments; and b) applying an experimental methodology to naturalistic observations (Grafen and Hails 2002; Dawkins 2007).

The method of *ethological observation* is grounded in a framework of four choices that the observer has to make, while observing three principles of experimental research. When planning an observation, the observer needs to choose (Dawkins 2007, pp. 73-88):

- 1- The '*level of observation*' – whether to observe individual animals, or groups, or body parts. For example, when testing whether herds of sheep protect their off-springs by keeping them surrounded by the adults during transhumance, the observation level is the group, such as familial units in the herd; while when studying if off-spring always move when their parents move, the observation level is the individual young);
- 2- The '*unit of behaviour*' – namely, the exact behavioural pattern to be observed (e.g. the approach of young towards their parents);
- 3- The sampling technique – which depends on what is available to observe, and what question the observer is trying to answer (e.g. when studying a rare behaviour, this should be recorded every time it is observed; when studying recurring behaviours, it might be more convenient to establish fixed periods of time and record them only when they are happening within those periods);
- 4- The type of record - whether the chosen behaviour has to be registered continuously (exact start and end each time it is performed; e.g. how long it takes to the young to get close to their parents) or as a point in time (e.g. just the occurrence).

The three principles of experimental research (Grafen and Hails 2002, pp. 76-85) require the researcher:

- a) to perform independent replications in order to treat data statistically and therefore detect whether events occurred by chance;
- b) to randomise the independent variable in order not to confound the many dependent variables that naturalistic environments present; and

c) to remove variation by comparing any manipulated conditions with either a control condition or a control group.

### *Ethological observation applied to this research*

Given its quantitative and qualitative characteristics, ethological observation is potentially an effective tool for identifying meaningful reactions that might be caused by the presence of a biotelemetry device on the animal's body. In particular, the controlled measuring of selected behaviours over time is especially suitable when it is uncertain which environmental variables might cause the animal's reactions (and thus when the observed behaviours might be easily misinterpreted if observed solely qualitatively). At the same time, the method also allows the observations of salient self-explanatory *incidents* to be analysed qualitatively. Since we wished to understand the WX of cats while they were wearing tracking devices, behaviours hypothesised as indicating discomfort were counted (see section 5.2, pp. 78-80), while overt behaviours toward the tag clearly showing discomfort were qualitatively described. This exploratory-and-experimental combination was particularly important for this research since it allowed us to interpret the cats' behaviours both in a generalised and individual fashion, and thus overcome the issues of misleading correlation (Dawkins 2007, p. 8) while appropriately accounting for individual differences (Feaver et al. 1986). Specifically, when the ethological protocol relies on statistical analysis for the interpretation, behaviour tends to be considered meaningful if its occurrence is statistically significant. In this respect, animals that show reactions different from the unit of behaviours chosen would be considered outliers and their behaviour dismissed as non-significant (Feaver et al. 1986). When evaluating the responses of individual animals to technological interventions, statistical analysis provides for reliability and validity of the behavioural interpretation (e.g. that a behaviour indicates discomfort). However, some individual behaviours that fall outside the hypothesised reactions might be especially meaningful, particularly if they are clearly directed at the device. For example, if an animal was to chew off components of the device but was the only individual of the sample population to do so and only did it once, this important behaviour might be omitted from the overall analysis or treated as an anomaly. However, for the purposes of designing animal-centred technology, that anomaly may indicate a very noteworthy design flaw. Hence, integrating the quantitative observational protocol with descriptive observations strengthens the methodology, especially when this is applied to the design context.

Although ethological observations are conventionally employed to study animals in the wild without intervening in their daily life, in order to measure the effects of tracking devices on animal wearers, we needed to include an environmental manipulation in the experimental design: fitting animal participants with tracking devices or prototypes. Once fitted with the devices, animals were observed conducting their habitual activities in their habitual environment, according to the conventional observation protocol. This approach allowed us

to measure and interpret the cats' behaviour in a relatively objective and reliable way, while minimally disrupting the participants' daily life. This was particularly important on both scientific and welfare grounds, since cats are commonly known to be prone to stress if their habits and environment get changed (Rochlitz 2005).

### **3.3 Prototyping stage**

After wearability requirements were heuristically established by the designers during the workshops, we used them to inform the physical design of a wearer-centred prototype tracking device. In HCI, prototyping allows designers to 'transform' a design hypothesis into an implementable solution with the aim of testing it (Hartmann et al. 2006). According to Hartmann (2006), prototypes are "*approximations of a product along some dimensions of interest*" and, by creating and testing them, developers learn what the redeeming features and the problems of a proposed design are. In fact, building prototypes is one of the four key activities in the design process, during which a requirements analysis leads to the sketching of alternative designs, which are converted into rough prototypes and tested, and then either improved or discarded in subsequent iterations (Preece et al. 2015, p. 15). In a UCD context, such a process involves users, ideally at every stage. In this respect, prototypes are employed to bridge the gap in perspective between the system designers (and their 'technical world') and the users (with their 'experience needs') (Gomaa and Scott 1981). In this research, cat wearers were the interactors of interest; thus, a prototype was developed to be tested with feline informants. Based on the requirements established by our workshop participants, we built an artefact to be tested with cats and thus evaluate whether the WCF had helped the workshop participants to design for cat wearability. Details of what requirements were used and how they were chosen are given in chapter 7.

### **3.4 Data analysis methods**

This section introduces the approaches used to analyse the variety of data collected through qualitative and quantitative data collection methods. Figure 3.1 in section 3.1 illustrates their application within the three-phase project.

#### **3.4.1 Document analysis**

Document analysis was used for selecting relevant information from the biotelemetry literature and deducing the elements of the WCF. The publications examined provided a very broad qualitative material including biological, ecological and technological aspects of biotelemetry interventions. Such variety of information necessitated the aid of a schematic approach, to recognise material linked to the physical design of a device and keep the focus on design aspects. Through a scheme based on the model for UX (Preece et al. 2015, pp. 19-30), information was categorised in general principles of design and other concepts. The analytical procedure used to categorise all relevant information is detailed in section 4.1 (pp. 60-64). It was obtained from a stand-alone document analysis method (Bowen 2009). Document Analysis is a systematic technique for reviewing, appraising, and selecting

written words in documents. It organises the selected text into categories to gain understanding of a perspective (Bowen 2009). However, on a traditional application of the method, for 'document' it is intended any manuscript that provides raw data from which to base an analysis rather than data already described and interpreted by another researcher (Bowen 2009). Seemingly, this would exclude academic publications, which by definitions are a product of data analysis, and therefore it would also exclude our biotelemetry paper selection. Nevertheless, in our case, the text of biotelemetry publications constituted raw data, since it provided the unorganised material that needed to be systematised. Hence, we examined excerpts reporting impacts, recommendations, and any variable related to animals to generate the WCF. This interpretation of the method is acknowledged by Bowen who recognises that there are special forms of research in which relying on previous publications is the only possibility (Bowen 2009).

### **3.4.2 Thematic analysis**

An abductive thematic analysis of the designer's dialogues that were registered during the workshops was employed as an evaluation method for exploring whether the WCF was a useful tool for designers. Thematic Analysis is a foundational method in qualitative research, a flexible process that allows investigators to identify and categorise the facets of a topic, and then make sense of them (Braun and Clarke 2006). In this research, we followed the six-step guide by Braun and Clarke on how to do and report a thematic analysis. This involves making six preliminary decisions prior to the analysis (enumerated in the 'a' group) and includes six implementing phases (synthesised in the 'b' group). (the steps do not have to be necessarily sequential (Maguire and Delahunt 2017)). They are reported as follow:

#### *Group a*

- 1a) Clarifying what counts as a theme.
- 2a) Determining whether to describe the whole data set which entails the loss of some detail or account for one or some particular aspects.
- 3a) Reporting whether an inductive or deductive (or abductive) approach is taken for identifying themes and patterns.
- 4a) Deciding whether to code data that have an explicit meaning (i.e. semantic level) or data that have to be interpreted for giving them a meaning (i.e. latent level)
- 5a) Choosing the epistemology that drives the analysis
- 6a) Clarifying the question(s) or focus that guide the coding and analysis



### *Group b*

1b) Familiarising oneself with the data by either transcribing them, if they are verbal, or reading through the whole data set before starting the coding process, if data are already written.

2b) Generating early codes from an initial list of ideas. Coding is a process that organises ideas derived from data and facilitates their interpretation (Silver and Lewins 2014, p. 158). Segments of data are assigned a code that summarises an idea and that enables, later on in the analysis, an easy search for patterns.

3b) Starting the analysis of codes. Codes (containing extracts of text) that evoke a similar concept are combined together into all-embracing containers called themes. This phase, called 'searching for themes' refocuses the analysis at a broader level and represents the interpretative part of the method. It is an iterative process in which the researcher goes back and forth the codes developing main themes, sub-themes, discarding some codes, aggregating or separating them. Once all the codes have been placed into a theme (or even discarded), the set of 'candidate' themes get revised.

4b) Refining candidate themes. This consists of aggregating, separating, or discarding at the theme level.

5b) Defining and naming the themes in the map. This is the way to start reporting what is interesting about themes and why.

6b) The final phase consists of providing evidence of the themes meaning.

In this analysis, what counted as a theme was given by the direct or indirect reference to the WCF (1a). The interest was in the similarities and divergences with the WCF for assessing how much the designers made actual use of it. For this reason, only the particular aspects of the data-set related to framework use were described (2a). Since the WCF was administered and explained before the workshop activities, we wanted to answer the question (6a) whether the designers' ideas, represented by their dialogues (realist epistemology according to which language reflects meaning and experience (5a)), were devised with the interposition of the WCF. Hence, some direct references to the WCF such as 'obtrusiveness', or 'acceptable' or 'imperceptible' were expected. However, the possibility of coding words or segments that were not part of the WCF was kept open. This choice was made to see if some dimensions missing in the framework were considered relevant for the designers. In this respect, we took an abductive approach (3a) at a semantic level of meaning (4a). The designers' dialogues were transcribed by the analyst (1b). Although the entire workshops were video recorded, videos were used for describing what designers were referring to when pointing at something without naming it during the interchange. After early codes were generated (2b) and collected into preliminary themes (3b), the themes

were reviewed by reading all the extracts inside them to see whether they appeared to reflect a consistent pattern. When they did not, we re-worked on them (e.g. discarding or creating new themes). Once consistency in each theme was reached, a thematic table was created (4b). Finally, each theme was defined (5b) to demonstrate whether the WCF was in effect used by the designers to establish their final set of wearability requirements (6b).

The software NVIVO version 11<sup>17</sup> was used for the analysis; it is particularly apt at managing and analysing textual source material. Through it, it is possible to generate and naming graphic containers called nodes, in which concepts of interest can be captured. This feature is typically used for coding purposes.

### 3.4.3 Behavioural analysis

All videos of cats' daily activity that we recorded during the observational studies were analysed with a focus on two categories of behaviours: a) explicit interactions addressed at the devices, and b) behaviours that are usual in cats but, if abnormally performed, may indicate some sort of discomfort<sup>18</sup> or stress (van den Bos 1998). In particular, we selected three such behaviours as potential indicators (i.e. grooming, scratching, and head/body shaking – details are given in section 5.2, pp. 78-80). In study 1, the explicit interactions were analysed qualitatively, by critically looking for incidents and describing these (*critical incident technique* (Flanagan 1954)), while the three potential indicators of discomfort were quantitatively measured by counting all occurrences and, when relevant, durations (*all-occurrences sampling*, (Lehner 1996, p. 197)) and by treating them statistically to understand if they were performed abnormally with respect to a control condition (section 5.3). In study 2, only a quantitative analysis was performed. We both measured whether explicit interactions occurred using a *one-zero sampling* technique (Lehner 1996, p. 202) and we counted the frequency of the indicators using the all-occurrence sampling.

#### *Critical incident technique*

Observations of explicit behaviours addressed toward the devices/prototype were analysed adapting the critical incident technique to animal behaviour. Flanagan (1954) described this method in the research context of psychology. However, the definition of the criterion for collecting observable activities (called incidents), where the “*purpose or intent of the act seems fairly clear to the observer and where its consequences are sufficiently definite to leave little doubt concerning its effect* (Flanagan 1954)”, fitted particularly well with the explicit interactions that some cats had towards the devices (for example, cuffing the device case with forepaws). In line with the tradition, such direct-interaction behaviours were found inductively as we examined the videos. The patterns we identified suggested potential

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<sup>17</sup> NVivo qualitative data analysis Software, QSR International Pty Ltd. Version 11.

<sup>18</sup> Following Wilson and McMahon (2006), this research uses the term ‘discomfort’ to describe a broad range of states in animals that cover everything from mild discomfort such as unpleasantness to more serious discomfort such as pain. The authors consider this term particularly suitable when referring to animal biotelemetry since it describes an animal’s perception keeping it neutral in respect to human feelings.

wearability requirements. These were derived based on the particular acts performed by the cats and their plausible reason. This is in line with Flanagan's reported studies that used critical incidents to identify critical requirements for developing procedures derived from particular performances of the studied subject. The process of analysing incidental behaviours from cats is detailed in section 5.3.2.

### *Quantitative analysis*

Observations of sampled behaviours were analysed as follows:

- 1) All-occurrences sampling: parameters such as frequency and duration were recorded on the pre-selected behaviours (i.e. grooming, scratching, and head/body shaking) during a determined period of time. This required the behaviours to be carefully defined and easily recognizable (Lehner 1996, p. 197). In section 5.2, we motivate and define the behaviours selected, and give details about type of parameters and time of sampling, and we describe the experimental design. We performed this analysis for the selected behaviours in both study 1 and 2.
- 2) One-zero sampling: this is a simple binary score that records the occurrence (one) or non-occurrence (zero) of a behaviour during a determined period of time (Lehner 1996, p. 202). Such sample period is usually short and there are several; however, we adapted the technique to have the parameter recorded only once, with either one or zero value, during the total time of observation. We performed this analysis for the explicit interactions showed by the cat participants in study 2 (section 7.2.1).
- 3) Statistical analysis: due to the high variation of causal factors in field studies, ethologists employ statistics as a way to infer causality. Causality factors are often difficult or impossible to identify, hence, statistics are used to measure such variability (Lehner 1996, p. 347). We performed a statistical analysis for study 1 in order to ascertain whether differences in counting among experimental conditions were important and ensure robustness of the selection of the behavioural indicators.

### **3.4.4 Triangulation**

In mixed-methods research, a variety of data derived from different methods and measurements is collected in order to better understand a phenomenon and/or to cross-validating findings (Jupp 2006). This strategy is called triangulation and compares data from at least two distinctive datasets (Jupp 2006). Matching findings from different sources increase the validity of the researcher's interpretation of the phenomenon under study. In this research, we used triangulation both to understand the wearer experience of cats and as a way of validating the WCF. *Triangulation of data* within study 1 was performed to understand a cat's experience in wearing devices. In this respect, incidents described qualitatively, and indicators measured quantitatively served to investigate and evaluate the degree of discomfort experienced by cats. To evaluate the WCF, we triangulated the

outcomes from the workshops and those from the observational studies in two ways. In the former, we accounted for both the designers and the cats to inform two sets of requirements: heuristically-derived by means of the WCF during the workshops and empirically-derived by observing cats. These two sets of requirements were then compared to see whether the wearability requirements that resulted from the application of the WCF during the workshops were equivalent to those that emerged from study 1. The second validation involved putting in relation the behaviours registered when the cats were wearing off-the-shelf devices with those registered when they were wearing the prototype, to see whether indicators of impact were less evident in the latter case.

### **3.5 Ethics**

The workshops and the two wearability studies with cats were approved by two Open University ethics committees: The Human Research Ethics Committee (HREC) for human participants, and the Animal Welfare Ethical Review Body (AWERB) for cat participants. Reference numbers are: HREC/2016/2202/Paci/1 and AWERB/2016/2202/Paci/1 (see Appendix 1). Human participants, that is workshop designers, and cat carers enrolling their pets as participants, received an information sheet explaining the objectives of the study, their right to withdraw at any time, and informing that no personal data related to them would be recorded; those who agreed to participate signed and returned a consent form (see Appendix 1). They were incentivised to attend the workshops or enrol their pets with small-value retailer vouchers.

In addition to the approval of The Open University's AWERB, study 1 and 2 were conducted in accordance with recently proposed animal-centred ethical frameworks for ACI research (Mancini 2017). This argues for the need to safeguard the welfare and respect the autonomy of animals involved in research at all times, while recognizing the need to engage with real-world situations in which the autonomy and welfare of the animals may already be compromised (Mancini 2017, p. 229). Unlike other felines, domestic cats (especially those living indoors) have a special relationship with their carers whereby their daily activities are limited or controlled. For example, carers decide about their roaming freedom, eating habits, reproductive abilities, etc., as well as deciding whether to fit their cats with bells, ID tags, or tracking collars. In fact, the practice of fitting animals with identification tags or biotelemetry devices on collars is accepted by many pet carers, wildlife researchers, and farmers. On the pet market in particular, many commercial products are available for cat carers to purchase and therefore wearing biotelemetry devices is becoming a part of the ordinary life experience of many domestic cats. These devices are sold as 'cat-friendly', presumably considered non-detrimental to the wearers' welfare. One aim of the study presented here was to test the hypothesis that even what are commonly considered 'cat-friendly' devices may in fact not be so and that better consideration has to be given to their

design from the wearer's perspective (Mancini 2017, section 10, principle 3, part 1). Therefore, those used here were two among many such devices.

*Mediated consent* (Mancini 2017, section 10, principle 2, part 1) for cats' participation was obtained from their carers. Prior to this, the relationship between prospective humans and cat participants was investigated by visiting the households and interviewing the humans to ensure that they had the best interest of their animals at heart. Invariably, the animal companions were regarded as members of the family and fitting GPS collars on their pets was deemed by the carers to be part of the influence that they normally exert on the autonomy of their cats in order to appropriately care for them.

*Contingent consent* (Mancini 2017, section 10, principle 2, part 2) from cats was also sought in the study. Albeit under the carers' supervision, cats were fitted with the devices by the researcher, which was only possible when the cat participants allowed the researcher to get close, handle them and instrument them with a foreign body. During the instrumentation process, none of the cats showed signs of fear, pain, or distress. Signs of dissent during the observations were monitored and discussed with the carers when occurring. Any cat that would have showed fearful or tense behaviour once instrumented would have been withdrawn from the observational sessions and released from the device. These cats would have been the participants with the highest score in negative experience, which would have been accounted for in the qualitative data analysis.

Although biotelemetry devices are habitually used on outdoor cats, indoor participants were chosen in this study, in order to ensure the highest standard of safety (Mancini 2017, section 10, principle 4, part 1). In fact, outdoor-roaming animals fitted with collars may incur risks. Although considered negligible by the device manufacturers, there is a risk that a tracking collar might get stuck in vegetation or other medium when the cat roams outdoors. Hence, choosing participants that lived confined in the household property (including enclosed gardens, balconies and courtyards) provided maximum safeguard of the participants' integrity. This was deemed the best methodological trade-off between the need to understand cats' requirements and the participants' safety. At the same time, the household constituted the participants' habitual environment, which minimized the impact of the study on them (Mancini 2017, section 10, principle 3, part 3).

Fundamentally, this research is concerned with assessing the experience that animals may have when interacting with wearable technology and with informing animal-centred designs of such wearables. This is in line with ACI's aim to improve the quality of life of animals coming into contact with interactive technology. Even though the cats that participated in this study were not normally subjected to biotelemetry practices, the study was deemed relevant and even beneficial for them (Mancini 2017, section 10, principle 3, part 1): in the short term, their carers learned about the effect that tracking devices could have on their cats and might thus avoid their use until better designs are available; in the

longer term, it is hoped that this research will inform such improved designs which those cats might one day be required to wear.

### **3.6 Chapter summary**

This research engaged with both qualitative and quantitative approaches in a three-phase project:

- 1) Phase 1: the analytical process that originated a first version of the WCF, which is the theoretical contribution of this research.
- 2) Phase 2: a two-step design stage in which a) three workshops were conducted with three different categories of designer participants, whose task was to apply the WCF and establish wearability requirements heuristically; b) a prototyping activity was conducted in which the requirements proposed by the designers in the previous step were implemented, leading to the generation of a wearer-centred prototype.
- 3) Phase 3: an evaluation of the WCF via triangulation of different datasets was conducted through a) the analysis of designers' dialogues when using the WCF, to understand whether it helped them think about wearability, and b) the analysis of animal's behaviours from two studies carried out with cat participants, to evaluate the effects of wearables on this species. The first study investigated cats' reactions to off-the-shelf devices. Its aims were to obtain a baseline against which to compare cat's reactions to the prototype, and to empirically establish wearability requirements to compare them with those established through the WCF. The second study measured quantitatively the effects of the prototype on cats and compared them with the effects recorded during the study in which the cats wore the off-the-shelf devices.

Overall, the use of a Mixed-Method Methodology was justified by the complexity of this three-phase design project, conducted within a multidisciplinary context, in which the interaction of interest was that of animal wearers with biotelemetry devices. This required the combination of qualitative (i.e. document and thematic analysis, and incidental analysis of animal behaviour) and quantitative (i.e. counting determined animal behaviours) techniques, as well as design practices (i.e. prototyping). In this respect, the generative and applicative phase (i.e. building the WCF, establishing requirements, physical prototyping) mostly benefitted from the application of a qualitative approach; while the evaluative phase, which was conducted with animals, required the application of a quantitative approach to yield a more objective interpretation of the data.

In the next page, Figure 3.2 illustrates the three phases of the research, the research activities involved and the links among them.

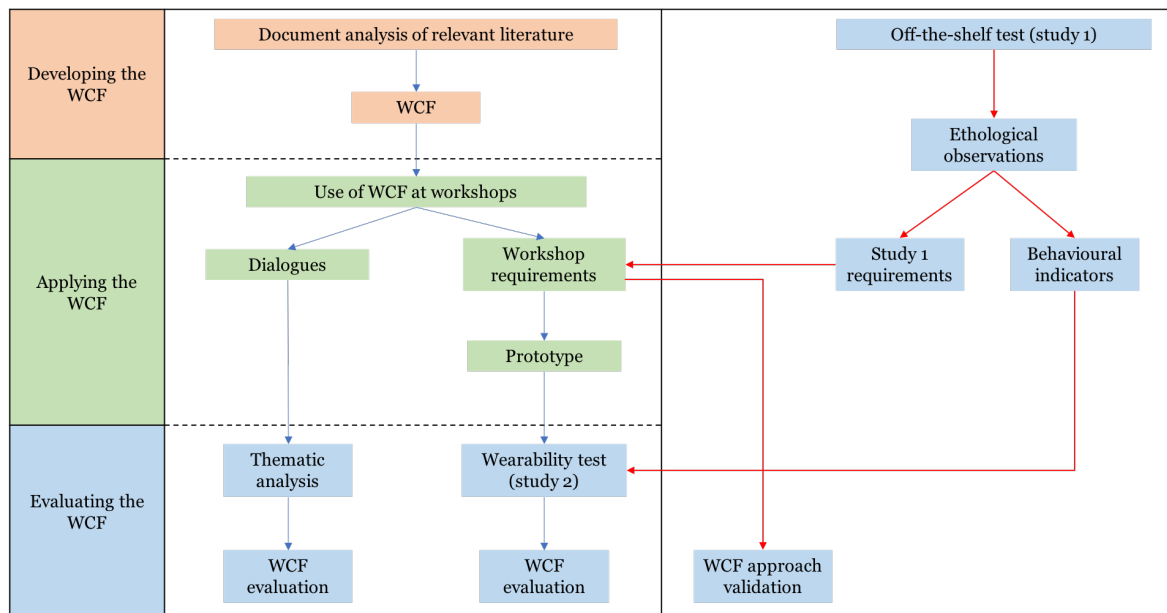


Figure 3.2: The three-phase research project, the research activities involved and the link between each activity.

**PART II**

**THE WEARER-CENTRED  
FRAMEWORK**



## 4. DEVELOPING A SYSTEMATIC WEARER-CENTRED TOOL: A Framework for biotelemetry designers

The overall conclusion of the literature review in chapter 2 showed the need for a systematic approach to designing for wearability in animal biotelemetry. Blackwell and Green's (2003) conceptualisation of frameworks as means to achieve systematicity in designing environments was deemed as the appropriate and necessary solution to address the main research question of this thesis (sections 1.2, 1.3, and 1.4). Thus, the aim of this research was developing a framework that would serve as a tool for establishing wearability requirements and guiding the design of wearable devices that would provide a good Wearer Experience (WX) (section 1.1). In this regard, the operative question was about what components might constitute a guiding framework for wearability (**Operative question 1** - *What elements might constitute such a wearer-centred framework?*). This chapter accounts for the analytical approach used to acquire relevant information from the biotelemetry literature and interpret it in design terms to form a first version of the Wearer-Centred Framework (WCF).

### 4.1 Developing the framework

#### *Rationale*

In chapter 2, we reviewed the biotelemetry literature to appraise the *extent* of the impacts caused by body-attached tags and to look at *current* approaches to address the problem. We understood that the issue is a substantial concern for bioteletrists and that the guidelines so far available to reduce impacts are not effective, as they make it difficult to render a systematic design that accounts for the many biological and technological variables at stake. This raised the question of how to systematically design wearables that impinge less and pointed to the concept of wearability as the key design goal to achieve. We proceeded by drawing a parallel between bioteletrists' guidelines (Kenward 2000; Murray and Fuller 2000; Morton et al. 2003; Hawkins 2004; Wilson and McMahon 2006; Casper 2009; Walker et al. 2012), which focus on animal wearers' needs, and the User-Centred Design (UCD) central value of conforming a design to users' needs (Gould and Lewis 1985). Specifically, bioteletrists advocate for body-attached tags to be more consistent with animal wearers' physicality, behaviours, and lifestyles to reduce adverse effects - and implicitly, improve their experience as wearers; likewise, UCD champions focus on users' capabilities, needs, and tasks to deliver a positive User Experience (UX) with the technology. Such concurrence prompted us to propose that systematically designing for wearability may help to deliver wearables that impinge less, much in the same way as systematically designing for usability helps delivering products positively experienced by users (Mao et al. 2005). Since UCD provides conceptual frameworks that support the systematic design of good UX, we made reference to these to develop our WCF and, thus, to achieve an equivalent systematisation of design for a good WX. Specifically, we initially

based our WCF on the model espoused by Preece et al. (2005, pp. 19-30), who promote the use of conceptual tools such as design principles, usability goals, and user experience goals to help designers to design for good UX. The authors refer to these as “*concrete means*” that “*orient designers towards thinking about different aspects of their designs*” (p. 25). We took inspiration from such UCD key drivers and reoriented them as criteria and abstractions for WX design for animals, since we aimed at providing designers with an equivalent set of concrete, orienting items to think systematically about an animal wearer experience. The next section presents the approach taken to gather information and derive the set of principles, values, and operational items that constitute the elements of the WCF, therefore achieving the first research objective articulated in section 1.2; the structure and components of our framework are described later in section 4.2.

### *Approach*

The components of the WCF were deduced from pertinent text excerpts, passages and quotations from reviewed literature, which related to device-induced impacts, tag features associated with negative effects, design guidelines proposed to minimise these effects, as well as animals’ needs, characteristics, activities and environments; this raw material was selected from representative papers, manuals, and technical reports of the biotelemetry literature; these were reviewed in sections 2.2 and 2.3 of this dissertation (Kenward 2000; Murray and Fuller 2000; Morton et al. 2003; Hawkins 2004; Wilson and McMahon 2006; Casper 2009; Walker et al. 2012). This information gathering followed a Document Analysis approach by which text within documents (see section 3.4.1 for our interpretation of what counts as a document) is examined and interpreted iteratively to identify patterns pertinent to the topic and organise them into categories (Bowen 2009). To systematise the process of text interpretation, we conducted a thematic-like analysis that involved sorting selected excerpts into both predefined and ‘emerging-while-reading’ conceptual containers. This abductive procedure, by which information expressing similar concepts is inserted into expected categories (deductive stage) or is used to generate new categories (inductive stage), produced consistent patterns that were used to derive the concepts and elements of the WCF.

### *Process*

Biotelemetry papers, manuals, and technical reports were initially identified by searching on Google Scholar for critical articles on the use of the biotelemetry technique by means of the keywords: ‘biotelemetry’ and ‘impact’. Casper (2009) was the first relevant item identified from which a snowball-like procedure for searching other similar publications was performed. Snowballing is a systematic literature review technique which uses the bibliography of an initial set of papers and scans it forward and backward to find other relevant papers to a point of saturation (Wohlin 2014); that is, when no new papers are found. However, in this research the procedure was mildly applied since the intention was

that of understanding the extent of impact derived by poor design, and current ways of addressing it, rather than covering every aspect of biotelemetry impact by performing a systematic literature review. Thus, differently from what is recommended for the conventional procedure by Wohlin (2014), the starting set consisted of a few papers and the search was stopped when we saw that the critical articles were recurrently cited within the general biotelemetry literature. In this way, seven scientific publications (reviewed in chapter 2) were found and their texts analysed. They were specifically:

- Chapter 2 of the book *Research Technique in Animal Ecology*, critically reviewing the effects of marking animals with electronic tags (Murray and Fuller 2000);
- One technical manual in *Animal Biotelemetry* illustrating use, implementation, advantages and drawbacks of the technique (Kenward 2000);
- One technical report in *Animal Welfare* describing device-induced impacts and proposing guidelines and recommendations (Morton et al. 2003);
- One critical paper from two major authors in *Animal Biotelemetry* expounding drawbacks and limitations of the practice (Wilson and McMahon 2006);
- One critical paper in the use of animal biotelemetry by an *Animal Welfare* author (Walker et al. 2012);
- Two major reviews by *Animal Welfarists*, describing impacts, reviewing tag design aspects, and proposing design recommendations (Hawkins 2004 and Casper 2009).

We started the selection process by looking for information related to *perception*, *obstruction*, and *acceptance* of a tag from an animal's perspective, deriving these concepts from the guidelines reviewed in chapter 2. We also deductively selected all the *animals' characteristics, activities, and environments* found in the text in order to account for the principle of having a focus on interactors. In other words, excerpts of the seven publications' texts related to tag wearability (e.g. device impacts, animal traits<sup>19</sup>, recommendations for improving the design, etc.) were selected and sorted into one or more of these pre-defined containers (i.e. perception, obstruction, acceptance, characteristics, activities, environments). At the same time, while reading the documents, the texts provided other appropriate information about, for example, devices' features, components and attachments relevant for describing WX, or other animals who, interacting with the wearer, produce an experience. Inductively, we created, and added to the scheme, categories representing these excerpts. Once all the relevant texts were organised, we reviewed the passages associated with each category (i.e. inside each conceptual 'container') to search for internal consistency. The information inside each consistent container was used to derive the concepts and components of the WCF. In this way, we derived design principles and

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<sup>19</sup> In ecology, a trait is “*any detectable phenotypic property [i.e. character] of an organism*” (Allaby 2010).

values for designing for WX as well as operational items that would help designers to operationalise the WX's principles and values to establish wearability requirements and design physical tags that afford good wearability for animals.

We report below some examples of how we used this process. In Casper (2009), potential impacts and recommendations (in *italics*) were used as follow:

*“Electronic devices may emit acoustic frequencies or light spectra to which animals are potentially sensitive. For example, some mammalian species use acoustic signals for communication and foraging and may modify their behaviour”*. This revealed that the perception of acoustic and light frequencies may generate a sensory and behavioural impact, which affects the wearer's experience in a negative way. In order not to have this influence, devices should not be perceived acoustically or visually, following the logic that if the device is not perceived, the stimulus exerted does not produce impact. This text excerpt was deductively coded as ‘perception’; at the same time, ‘sensory abilities’ was inductively recognised as a new conceptual ‘container’. In short, this passage was interpreted to infer the idea that *sensory imperceptibility* is a design **principle** for animal wearability, and it became an element of the main box containing all the principles found through this process. Also, this quote specified the kind of sensory capability (*hearing*, and *sight*) and activity (*signalling for communication*, and *foraging*) that involves that sensory capability. Thus, the passage was also used to identify animal characteristics and activities pertinent to wearability that would help designers to apply the principle. In summary, through this excerpt the principle of sensory imperceptibility was derived, meantime hearing, sight, animal communication, and foraging were extrapolated as important animal characteristics and activities to be considered.

*“Enlarging the profile of an animal that burrows or moves through dense vegetation or narrow openings, such as winter-ice holes, may impede its normal movements, cause it to expend extra energy or become entrapped”*. Multi information was collected from this excerpt. Firstly, it mentioned the animal body shape (that is, enlarging the profile). Secondly, the excerpt highlighted that each animal lives in species-specific environments (e.g. burrows, dense vegetation, and narrow openings). Thirdly, both body shape and environments might have a role in determining the wearability features of a device, as evidenced by the statement that the profile of the device (or the animals' profile as altered by the device) might cause the wearer to become obstructed or entrapped. Therefore, in order to prevent the wearer from bumping into surfaces, getting caught, or expending additional energy, tags should not impair physical movements. This passage enabled us to infer another principle, *physical unobtrusiveness*, as well as to identify other particular animal characteristics, environments, and activities (i.e. body shape, close or open spaces, locomotion) that would help designers to apply the principle.

“The colour of equipment may influence the behaviour of animals, their social status and their vulnerability to predation”. This suggested that device features may potentially influence different individuals, such as wearers and other animals interacting with them. Thus, this extract was used to derive an **interactors** component in which the *significant-others* element accounts for the fact that the wearers need to be considered in their social (e.g. living in group) and ecological (e.g. prey/predator relationship) context.

With this procedure, the structure and content of the WCF was developed; this is illustrated and described in the next section.

## 4.2 The WCF and its elements

In the previous section, we described the process of how considerations and recommendations, such as those of Casper (2009), were fitted into a coding scheme from which the WCF was originated. In short, biotelemetry authors point out that tags should not interfere with animals’ daily activities, or social interactions; in so doing, these authors refer to particular characteristics, activities or environments of an animal (e.g. body shape, sensory capabilities, or way of locomotion) which vary with the biology of the species. On the one hand, this specificity helps to establish wearability requirements, on the other hand, it constrains the design of the device thus potentially generating conflicts with (human) user requirements, given a system’s technical capabilities and constraints. These assumptions have served as the basis to identify the WCF components and their connections. Figure 4.1 illustrates a visual map of the first version of the WCF.

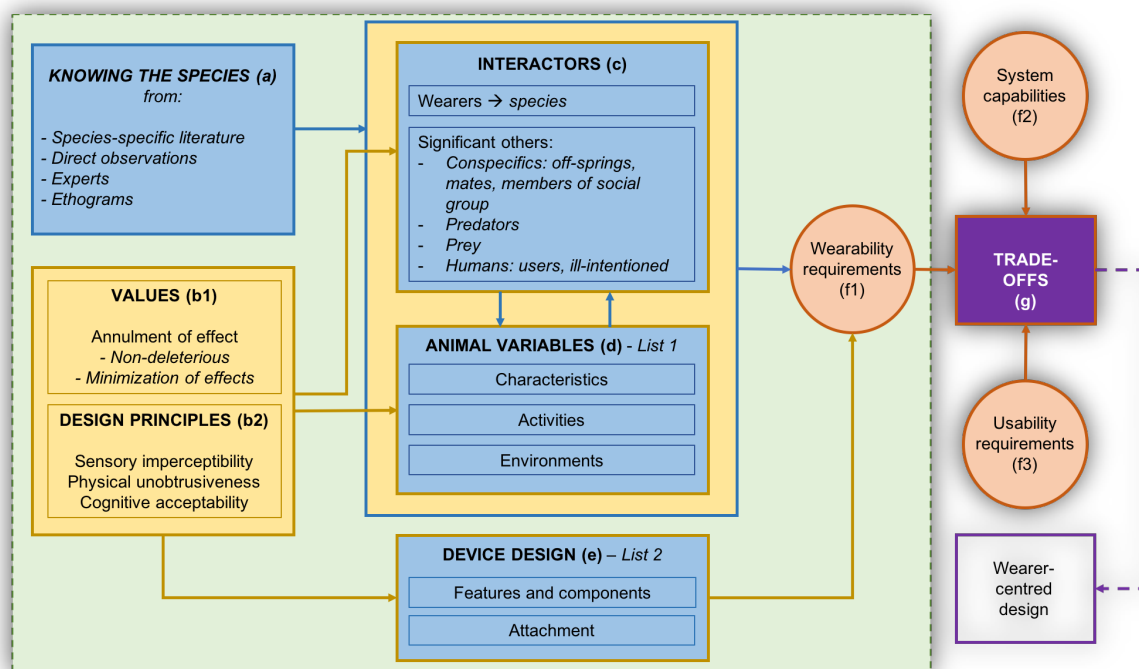


Figure 4.1: Components and connections of a first version of the Wearer-Centred Framework (WCF). Its nine elements (knowing the species (a), design principles and values (b1 and b2), interactors (c), animal variables (d), device design (e), wearability, system capabilities and usability requirements (f1, f2, f3), and trade-offs (g)) are represented as boxes and ovals of different colours to distinguish their function. The yellow box represents the general principles and values that inform wearability. The blue boxes are ‘operational’ items that helps to establish wearability requirements step by step. The orange ovals are the resulting requirements

*related to animal wearers, human users, and of the electronic components. The purple box is concerned with the resolution of conflicts among requirements. The framing green background represents the focus of the WCF, while the establishment of usability requirements and system technical capabilities, and the resolution of conflicts is remitted to other existing or future frameworks.*

In detail, the WCF is composed of nine main interconnected components as shown in Figure 4.1. The yellow box represents the general values and principles that inform wearability and that are valid for the design of any wearer-device interaction in the context of animal biotelemetry. The blue components are ‘operational’ items that assist designers to concretely establish wearability requirements with respect to the animal species involved and the type of device that has to be designed. The (human) users’ requirements (orange circle) are also acknowledged; they are traded-off (purple box) with the animals’ wearability requirement, given systems’ capabilities and constraints, when conceptualising and implementing alternative designs to achieve good wearability in a feasible and useful manner.

Below, each component is explained in more detail.

#### a) **Knowing the species**

It refers to the fact that it is fundamental for a biotelemetry designer to acquire biological information about the species of interest if a wearer-centred design is the goal. Designers are unlikely to have a species-specific knowledge of animals’ biology, anatomy, and environments. Gulliksen et al. (2003) suggest that “*there should be an experienced usability expert on the development team*” to “*decide on matters affecting the usability system*”. Analogously, the WCF proposes likely means that can help deciding what might affect the wearability of the device. In particular, four means to achieve this are identified: consulting species-specific literature, observing directly the tagged individuals, including animal experts during the design activities, and using ethograms.

#### b) **Design values (b1) and principles (b2)**

These are ‘conceptual triggers’ adopted in UCD to guide developers to design for good usability and user experience (review in: (Preece et al. 2015, pp. 19-30)). These values and principles suggest what an interface should or should not aim to do from a user’s perspective at an abstract level, for example, whether a device should give a sensory output. However, as Preece and colleagues state: “[principles] *are not intended to specify how to design an actual interface, [...] but act more like triggers to designers, ensuring that they have provided certain features at an interface*” (Preece et al. 2015, p. 26). The WCF proposes a design value and three design principles for wearability to inform the design of wearables that provide good WX.

The key value is **annulment of effect** and it accounts for the moral imperative and scientific benefit of nullifying potential negative effects of a tag. When the ideal condition of not producing an impact is impossible to achieve, efforts should be made to minimise the

effect and in no circumstance it should be acceptable that the tag harms the wearer, especially if the damage puts the life of the wearer at risk (for example, some types of tag's attachment can potentially get caught and increase the risk of entanglement with consequent impact on survival). The overall value was derived from unanimous statements shared by the whole biotelemetry community and ascribable to a universal common sense. In detail, minimisation of effects refers to the postulation that all effort must be taken to minimise the burden of the transmitter and the attachment (Wilson and McMahon 2006), and non-deleteriousness refers to the assumption of biotelemetry that the *"tagging and presence of the device do not deleteriously affect the individual"* (Cooke 2008), and those *"who tag animals have a moral as well as a practical obligation to ensure that there is no adverse effect on their subjects"* (Kenward 2001, p. 123).

The three principles pertain to sensory, physical, and cognitive experience that an animal might have due to the presence of a tag. They were derived by reasoning that, if animals do not actively use or engage with a device for their own purposes (as is the case with biotelemetry tags), arguably a good WX means having no experience at all. This is consistent with what all existing welfare guidelines seem to point to: that tags should be designed in such a way that they do not get in the way of the animal's daily experiences, activities or social interactions. Assuming that an experience can be sensory, physical or/and cognitive, the WCF promotes the following:

### ***Sensory imperceptibility***

This means that a device should not be perceived by any of the wearer's senses. It refers to a wider range of senses in comparison with those of humans (e.g. electro-receptive animals can sense the electric fields emitted by the tag (Keinath and Musick 1993)) as well as to a wider spectrum of sensitivity (e.g. birds such as raptors may perceive coloured devices at a much greater distance than humans do, thanks to their very acute and pigmented vision (Jones et al. 2007)). Ideally, any tag would be imperceptible; since experience is primarily mediated through the senses, if the senses cannot detect a tag, there is no experience of it.

### ***Physical unobtrusiveness***

It refers to the fact that, for example, a tag should not impede limb movements or access to locations. It is linked with locomotive abilities (e.g. swimming or flying movements can be limited by a tag attached in an improper location) as well as environmental features (e.g. dense vegetation can impede smooth movements of animals due to the presence of obtrusive tags (Kenward 2000)). It may be that a tag is perceived by the wearer but, if it is not obtrusive, then the experience is likely to be less intense; on the other hand, obtrusion is likely to intensify any sensory experience the wearer might have of a tag.

## ***Cognitive acceptability***

This is related to whether animals express the need to remove a tag they are wearing because they do not accept its presence. This can lead to the development of atypical behaviour such as stereotypes (detrimental compulsions that may arise when individuals cannot express their natural behaviour – e.g. because of the tag presence). It may be that a tag is perceivable and obtrusive, but the wearer still finds it acceptable. On the other hand, if the wearer finds the tag to be unacceptable, the impact on their experience can be significant whatever the sensory perceptibility and level of obtrusiveness.

### **c) Interactors**

It refers to wearers and individuals significantly interacting with them. This component was inductively derived from the analysis of the text in biotelemetry publications, where welfarists posit that attention must be paid to inter- and intra-specific interactions. Animals are part of wide ecologies, social networks and activities (Walker et al. 2012). Hence, the principles and values for wearability do not just relate to the wearers themselves, but they also pertain to other individuals significantly interacting with them. Ecological and social contexts need to be considered from the perspective of all related interactors, if we are to achieve wearer-centred design. The WCF identifies two classes of interactors: the wearers themselves, and *significant others*. Among significant others are included conspecifics such as off-springs, sexual mates, or members of the same social group, and potential prey and predators of the wearer, whose interaction with the wearer could be significantly altered due to the device. For example, a potential mate might perceive the tag of an individual, experience it as physically obtrusive, or find it cognitively unacceptable, thus preferring non-instrumented partners instead of the tagged individual (e.g. Burley et al. (1982) found that both genders of zebra finches avoided light-blue and light-green-tagged mates, while females preferred red-tagged males, and males selected black and pink-tagged females). Also, humans are a category of significant others both because they may be the users of the technology (e.g. wildlife researchers, pet or farm guardians) or because the technology may enhance their chance to encounter tagged wildlife (e.g. poachers that may identify more easily tagged animals).

### **d) Animal variables**

It refers to characteristics of interactors, their activities, and environments, consistent with their biology and lifestyle. This element highlights that each animal has species-specific capabilities and environments which vary across the animal kingdom. They depend on the biology of each species, and their specificity informs the establishment of device requirements. This component of the WCF derived from the user focus proposed by Gould and Lewis (1985) to which the “[interactor]’s goals, tasks and needs should early guide the development” (in: Gulliksen et al. 2003). This was adapted to the context of animal



wearability, by which characteristics, environments and daily or seasonal activities of the animals are key to understand the interactors' needs (instead of the user's task). The WCF accounts for the wearer and significant others' characteristics, activities and environments, listing a range of biological variables (List 1 in Appendix 2) that have been extrapolated considering the biology of a wide range of vertebrate animals (i.e. fish, amphibians, reptiles, birds, and mammals).

e) **Device design**

It refers to the physical and functional aspects of a tag which are the object of a wearer-centred (re)design. This component of the WCF serves as a reminder of the various features of a device that have to comply with the animal's characteristics, activities and environments. It was created collecting all the features, components and types of attachment described in the text of biotelemetry publications and it includes a list of said features, components and types (list 2 in Appendix 2).

f) **Device capabilities and requirements (f1, f2, f3)**

Among them, **wearability requirements (f1)** are the outcomes of the requirements analysis carried out by applying the WCF elements so far described. The focus of the WCF is about reflecting on animal wearer needs to establish wearability requirements; however, since human users have their own needs and since technological constraints may render wearability requirements hard to design for, the WCF also considers the requirements of the users for **usability (f3)** as well as the constraints imposed by the **system (f2)**, although defining how these other requirements and constraints should be established is beyond the scope of this work. Considering the needs of the different stakeholders (animal wearers and human users) as well as technological capabilities and constraints allows us to conduct an analysis across conflicting requirements, which is necessary to achieve practical solutions for biotelemetry applications that are both appropriately wearable and functional.

g) **Design trade-offs**

It refers to the importance of managing possible conflicting requirements. This is important because in some cases an instrument's species appropriateness may not be achievable, given current technological capabilities. To develop wearer-centred biotelemetry technologies that do not impinge on animals' welfare, devices should be entirely unobtrusive, therefore allowing individuals to perform their daily activities and behaviours entirely undisturbed. While entirely neutralising technological impacts may not be possible, one important function of the WCF is that it can help designers to analyse possible requirement 'divergences' and, when necessary, negotiate the best possible trade-offs between wearability and usability requirements, given available technological capabilities. Such trade-offs are therefore obtained from the intersection between what kind of data human

users need to collect and what is an acceptable impact for animals, given what technologies are currently available.

### 4.3 How the framework should work

With reference to Figure 4.1, given the availability of resources (e.g. animal experts, ethograms, etc.) that allow a designer to understand the species of interest (a), the values and principles of wearability (b1 and b2) would help the designer to identify the set of animal variables (d) that inform the wearer needs relevant for the interactors (c). Principles and values also would help to individuate device features, components and attachments (e) that need to be (re)designed to achieve wearability in relation to the set of variables identified. The combination of wearer needs and device design establish the wearability requirements. Wearability and usability requirements, along with system capabilities (f1, f2, f3), need to be traded-off (g) in order to identify possible designs that provide optimal wearability and functionality. The WCF focuses on what is ideal for the wearer; user requirements and system capabilities are analysed to elicit trade-offs, but they are informed by other frameworks (e.g. user- or system-centred). Ideally, the WCF is applied as follow in the next section.

#### 4.3.1 How to operationalise the framework: An example

The following simplified example illustrates how the framework can be operationalised to systematically establish requirements for the design of wearer-centred tags.

##### *Relations among the WCF components*

Consider a wildlife project that makes use of trackers to monitor a North-American population of red foxes<sup>20</sup>. Biotelemetrists aim at using devices that do not affect the individuals being monitored. Wearer-centred designers are involved in the design of the tags. As they use the WCF as a guiding tool, they recognise foxes as the wearer interactors and start applying the principles one at a time. Designers firstly focus on the **principle of sensory imperceptibility** for the sense of hearing and aim at designing an aurally imperceptible tag. They consult an **animal expert** to acquire the relevant information regarding the **wearer and the wearer's significant others**. The WCF assists them in considering who the prey and predators of foxes are, which *hearing capabilities* are involved (e.g. which frequencies are audible by the species of interest), which critical and delicate **activities** may be influenced by the tag (e.g. by interfering with mating calls, alerting and dispersing prey, or disrupting ambushes), and which **environments** have to be considered (e.g. type of habitat that propagates sound). This assists in determining which needs the interactors have. Next, electronic **components** of the device that may be responsible of frequency emission are individuated. **Wearability requirements** for a

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<sup>20</sup> Specific denomination: *Vulpes Vulpes*.

device are established in relation to the components that need to be (re)designed and in relation to the sensory characteristics of foxes and of their significant others.

### *Establishing wearability requirements*

The possibility that a biotelemetry tag might emit ultrasounds audible to animals has been demonstrated by studies on bat dataloggers, which revealed the emission of ultrasonic bands in the measure of circa 33,000 Hz (Willis et al. 2009). In this respect, the WCF prompts designers to assess the presence of detectable radiation from the device in relation with the aural capabilities of all the animal species that are likely to be involved or affected (i.e. instrumented animals plus their significant others within the geographical context and distribution area in question). Experts are questioned about the matter. In this simplification, foxes have an audiogram within the approximate range of 51-48,000 Hz (Malkemper et al. 2015) (for comparison: humans' audiogram is commonly 20-20,000 Hz). The audiogram of foxes' significant others varies: their typical prey, mice, have an aural sensitivity of circa 1,000-91,000 Hz<sup>21</sup>; their potential (but not regular) predators/competitors living in the studied area, coyotes<sup>22</sup>, are likely to have an aural sensitivity of circa 67-45,000 Hz (although their exact hearing range is not known, it is likely similar to that of canids such as dogs<sup>21</sup>). This means that in order to meet the hearing requirement (consistent with the principle of sensory imperceptibility), a device used on foxes should not emit auditory signals within the frequencies of 51-91,000 Hz, which is the combined minimum and maximum frequency hearable by at least one of the three species.

Figure 4.2 summarises the abovementioned requirement analysis for hearing: if the wearer, or the individuals interacting with him, are able to hear particular frequencies that may be produced by a device, the principle of sensory imperceptibility prescribes that the designer should avoid design solutions that involve acoustic signals, or technologies that may produce a vibration, in the range audible by the wearer and their significant others. In this example, this means that sound actuators that produce frequencies from 51 Hz to 91 kHz should be avoided.

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<sup>21</sup> Strain GM (2003) How well do dogs and other animals hear? Web page (accessed 7 November 2018) - <https://www.lsu.edu/deafness/HearingRange.html>.

<sup>22</sup> <https://www.smithsonianmag.com/science-nature/foxes-and-coyotes-are-natural-enemies-or-are-they-180968424/>.

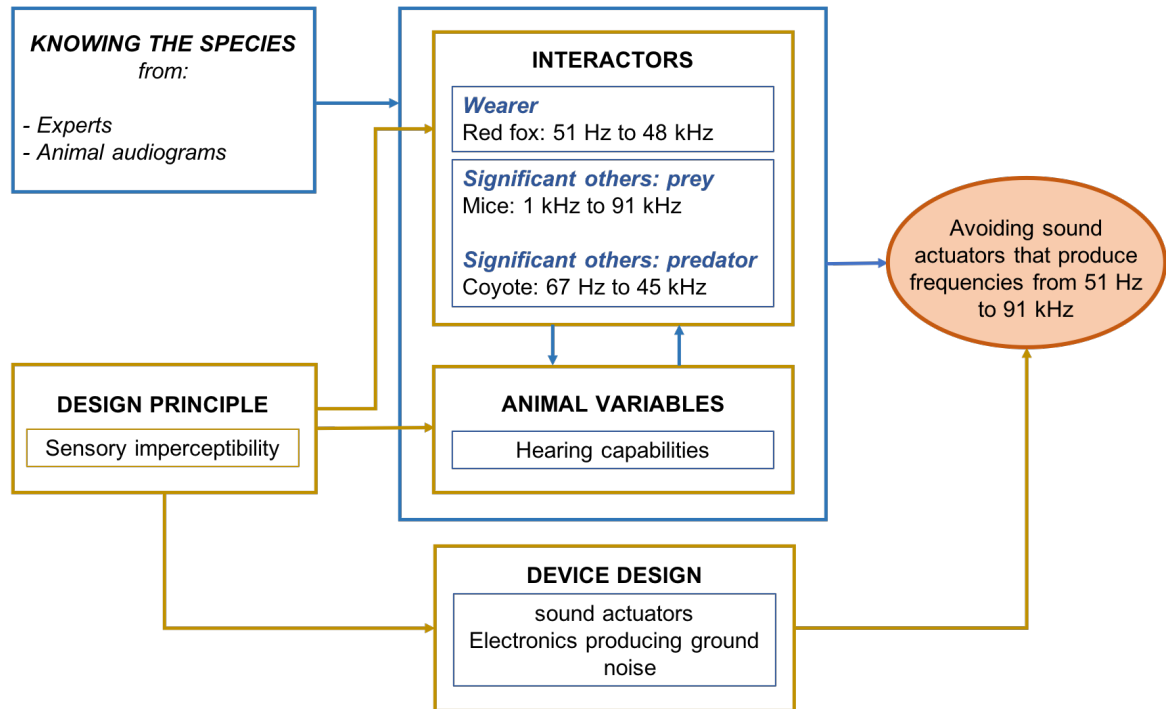


Figure 4.2: Foxes listen frequencies from 51 Hz to 48 kHz, while their typical prey, mice, hear ultrasounds from 1 kHz to 91 kHz. Coyotes' range is in between. The device, in order to be aurally imperceptible, should not produce frequency in the range of 51 Hz and 91 kHz which are the minimum audible by a fox and the maximum by a mouse.

### Managing trade-offs

If the envisaged tag does not produce any noise within the 51-91.000 Hz range, then the hearing requirements related to the sensory imperceptibility principle are fulfilled. On the contrary, if the technology the designers propose to use generates a resonance, the device design should be revised and technologies that do not produce ground noise in the 51-91,000 Hz span should be used (or designed) instead. Should this not be possible due to current technological limitations, trade-offs should be considered following a scale of importance, where the importance of a requirement should be determined by the severity of the expected impact produced by the electronic tag on the wearer if said requirement was not met. To continue with this example, as mentioned above, coyotes are accidental predators/competitors of North-American foxes, while mice are regular fox quarry. Thus, the predatory impact of coyotes on vulpines is less significant than fox hunting failure on mice, which can lead to starvation, especially because mice rely on their very highly sensitive hearing system to escape predators, whereas the hunting behaviour of coyotes on foxes is principally driven by smell (Mazis 2008). Therefore, starvation being a more likely impact to occur than being attacked by coyotes and hearing being a primary sense used by mice to defeat predation, designers need to prioritise the hearing capabilities of mice and make sure that any acoustic emissions from the device fall outside the mice's hearing range, where total sound avoidance is not possible.

The same assessment process should be carried out for each known significant other (e.g. mice are not the only prey foxes rely upon) and for all of the relevant variables associated

with the biological and environmental characteristics of the animals in question. More specifically, these are related with the sensory, physiological, morphological and psychological characteristics of animals, their physical and social environment, their living conditions, daily activities, behaviours, and movements (List 1 in appendix 2).

#### **4.4 Chapter summary**

This chapter has focused on how the WCF was developed and has presented its elements and connections, thus answering the first operative question of this research (*What elements might constitute such a wearer-centred framework?*). Drawing from theories about the efficacy of frameworks to achieve systematicity in interaction design, the WCF is proposed as an aiding tool to systematically eliciting wearability requirements, which is a necessary process to understand how a biotelemetry product could achieve good wearability and wearer experience. Keeping the value and principles for wearability in mind, this research considers their application for a systematic requirements analysis in relation to the animals' sensory (e.g. hearing, sight), physiological (e.g. energetics), morphological (e.g. animal body shape, size), behavioural (e.g. kind of movements), and environmental variables (e.g. aquatic, terrestrial organisms), and to those of their significant others. Arguably, being able to identify requirements, and predict the potential impacts of prospective applications as accurately as possible before entering the iterative design cycle of a wearable device is of critical importance in the design of animal-centred products. To establish such requirements, arguably the widest possible range of design variables should be considered in accordance with design principles such as the ones proposed above.

The WCF here proposed is not intended as a final version but as the first framework of its kind that will need to be refined and incrementally improved with the acquisition of new knowledge. Nevertheless, this version was used for conducting a requirements analysis to explore how the framework would have worked and what outcomes (in terms of requirements) would have been elicited from its application. This is reported in chapter 6. In the next chapter 5, the first observational study of this research involving cat participants is described. This study (study 1) served as an evaluative tool and its findings were used to triangulate the findings of the other studies presented in this thesis (i.e. workshops and study 2), in order to validate the WCF as a useful tool.

# **PART III**

## **EMPIRICAL STUDIES**

## 5. WEARABILITY OF OFF-THE-SHELF DEVICES: Study 1

Study 1 was carried out independently of the development and application of the WCF. The aim was to investigate cats' experience of wearing off-the-shelf devices marketed as suitable<sup>23</sup> and comfortable for cats<sup>24</sup>, in order to understand the extent of such suitability and comfortability, and to identify any possible wearability flaws that might require a re-design. By employing an ethological approach (section 3.2.3), two kinds of data were collected: usual cats' behaviours that in stressful circumstances might be performed abnormally, and cats' behaviours that seemed to be explicit interactions clearly directed at the device. These behaviours were analysed to identify signs of discomfort and any design flaws that might cause the behaviours and help establish wearability requirements directly elicited from animal participants. In order to evaluate the WCF, 1) the wearability requirements identified during study 1 were then compared with the wearability requirements resulting from the workshops in which the WCF was used to inform the design of a prototype tracking collar for cats (chapter 6); and 2) the behavioural responses identified during study 1 were put in relation with the behavioural responses identified during a second wearability study, in which the prototype tracking collar resulting from the workshops was evaluated (study 2 – chapter 7). This chapter motivates the reason why study 1 was deemed necessary (section 5.1), it describes the experimental protocol (section 5.2) and data analysis (section 5.3), and it reports and discusses the findings (sections 5.4 and 5.5).

### 5.1 Why study 1 was needed

After the WCF was developed, teams of designers were asked to use it during a series of workshops to heuristically establish wearability requirements for a cat tracking device and to use such requirements to propose wearer-centred mock-ups (chapters 6). The assumption was that if the WCF is a useful tool, it is likely the requirements established by its use will inform a physical design that affords good wearability. But, in order to assess the usefulness of the framework, we needed to compare the wearability of devices whose design was informed by the framework against the wearability of equivalent devices whose design was not informed by the framework. Fundamentally, we also needed to establish a way of understanding and acquiring the perspective of the animal stakeholders. Thus, we conducted a first observational study with cat participants to evaluate the wearability of existing tracking devices and identify behavioural measures of wearability, before evaluating the prototype designed using the framework in a wearability study, using the same behavioural measures, to assess whether the use of the framework had resulted in an improvement of the wearers' experience.

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<sup>23</sup> From <https://tractive.com/en/pd/gps-tracker#/>: FAQ section - "*Can the Tractive GPS Tracker also be used for cats?*". Answer: "*yes, the Tractive GPS is suitable for all animals above 4.5 Kg, including cats!*"

<sup>24</sup> From <https://www.pawtrax.co.uk/why>: "*HALO Tracker is ergonomically designed and comfortable for cats*".

To the best of our knowledge, we did not find any work on the analysis of cats' behaviours while wearing devices to assess their wearer experience (WX). In the Animal Behaviour literature some investigations were conducted on impacts in cats wearing trackers; for example, Coughlin and van Heezik (2015) recorded movement patterns and distances that outdoor individuals covered with GPS units of varying mass, to see whether their roaming habits were affected by the burden of the tags. However, their analysis did not account for behaviour showing a direct interaction with the devices. Another study by van den Bos (1998) measured the behavioural responses of cats to stressful situations, such as living confined in groups. However, the study was not concerned with assessing the level of stress caused by an interactive experience with biotelemetry devices and did not employ biotelemetry at all.

In order to understand how cats react when they wear a device and what behaviours might convey discomfort, we designed an experimental protocol to systematically record observations of cats' behaviours while wearing devices and interpret their responses to the presence of the wearables (study 1). Participants were fitted with two off-the-shelf tags and their responses were analysed both to identify indicative behaviours of device-induced discomfort (intended as reactions to a stimulation) and to individuate flaws in the physical design of the tags. The indicators were subsequently used during the wearability test of the prototype informed by the framework (study 2) to relate behavioural occurrences against those registered during the wearability test of the off-the-shelf devices (study 1). At the same time, the wearability flaws identified during the first study served to establish a set of requirements directly derived from the cats' experience, which were then compared with the requirements identified heuristically using the framework during the workshops. In summary, we needed this first study for two of the research objectives articulated in section 1.2: a) to be able to determine what a cat's experience of wearing a device might be and, consequently, to assess wearability, and b) to cross-validate the WCF by using indicators of discomfort to be measured in a subsequent wearability test of the prototype and to empirically establish requirements to be compared with those heuristically established during the workshops.

## **5.2 Experimental protocol**

We worked with 13 indoor feline participants. We opted for working with potential wearers of tracking technology; these were indoor individuals whose reactions to monitoring devices their keepers were interested in understanding before potentially purchasing any such devices for their pets. Observing indoor individuals was important to enable the observer to keep the cats in view constantly and record their behaviours throughout the whole observation period, with the advantage of observing them in their habitual environment. Among the 13 cats monitored, eight were male and five females. The average age was 7.1



years (s.d. = 2.46) and the average weight was 6.0 kg (s.d. = 1.21). Detailed information for each cat regarding age, weight, and hair length is reported in Table 5.1.

Cat ID	Age (y.m.) <sup>25</sup>	Weight (Kg)	Hair length
C1	7.6	5	Short
C2	7.6	5	Short
C3	8.1	7	Medium-long
C4	4.4	8.6	Medium-long
C5	5	4.5	Short
C6	3.6	5.5	Medium-long
C7	9.9	7	Medium-long
C8	9.9	7	Medium-long
C9	9.7	7	Medium-long
C10	4.7	5.5	Medium
C11	4.7	5	Short
C12	9.1	6.5	Medium-long
C13	9	5	Short

Table 5.1: Cat participants information.

We tested two commercial GPS tags, respectively called PawTrax® Halo<sup>26</sup> and Tractive®<sup>27</sup>.

PawTrax® Halo (Figure 5.1) consists of a tracker contained inside two curved black boxes hinged together along their shorter side. This allows the casing to flex at its centre and to bend around the cat's neck within a range of 20mm-extension (with a minimum length of 80mm to a maximum of 100mm). The case is 21-millimetres wide, 8.3-millimetres thick, and it weighs 21.7 grams (which made it the lightest GPS for cats available on the market at the time of the study). It has two distal and two central specular eyelets through which a rubbery and elasticated 13.5mm-wide collar (5g) can slide. Velcro® is used to fasten the two edges of the collar. The device is supplied with two yellow reflective strips.



Figure 5.1: The PawTrax device. On the left, the two black cases hinged together and completely bent; on the centre, the collar attached to the case with an old UK pound coin for scale (coin: 23mm diameter); on the right, the device worn by a cat participant.

Tractive® (Figure 5.2) consists of a tracker contained inside a white case sizing 51x41x15mm and weighing 41.2 grams. The case is attached to a 9.4mm-wide black leather collar (8g) by means of a snap-fit clip. The collar is fastened onto the cat's neck through a buckle.

<sup>25</sup> The average lifespan of domestic cats is considered to be circa 16 years (Teng et al. 2018).

<sup>26</sup> [www.pawtrax.co.uk](http://www.pawtrax.co.uk).

<sup>27</sup> [www.tractive.com](http://www.tractive.com).



*Figure 5.2: The Tractive device. On the left, the white case; on the centre, the collar attached to the case with an old UK pound coin for scale (coin: 23mm diameter); on the right, the device worn by a cat participant.*

During the study, for each cat, the collars were fastened following the fitting guidelines of the manufacturer, which recommend attaching the collar so that two fingers can be inserted between collar and neck. This is also recommended by collar sellers to ensure a comfortable fitting for the animal. We chose two substantially different tag models in order to investigate distinct aspects of a physical design, such as various sizes, weights, materials, colours, textures, and shapes. Since we were interested in studying wearability aspects of the devices, rather than in locating the animals, the trackers were not activated.

In order to understand the cats' experience of wearing a tracking collar and investigate which elements of the devices might affect the wearers and how, we systematically observed the cats and measured their behavioural reactions to the presence of the devices. The experimental protocol was as follows: each cat was observed for three different non-consecutive days, each day under a different experimental condition: 1) not wearing anything (control condition), 2) wearing the PawTrax, and 3) wearing the Tractive. Conditions were assigned randomly to avoid order effects<sup>28</sup>. Each cat wore each device for 6 continuous hours during the corresponding day of observations, at the end of which the tag was removed. However, they were effectively observed for 20 minutes every hour, for a total of 120 minutes per day (i.e. 20 minutes for each of the 6 hours). This was done with the aim of observing the cats during a range of daily activities (e.g. resting, eating, walking), without tiring the observer, who otherwise would have to perform 6 consecutive hours of observations. Although cats are usually more active during night time, observations occurred during daylight hours. This was a constraint from the keepers, who were not available for nocturnal experiments. During the observation period, the observer did not interact with the cats but followed throughout and discreetly video-recorded them, so as to minimise the observer's interference. When the cats were hiding (e.g. under a bed), the camera was positioned in such a way as to allow the recording, so that monitoring could continue. Ten cats were familiar with the observer, who had visited their homes in various previous occasions before the observations were carried out. The other three cats were habituated for half an hour to the presence of the observer, and they were monitored with

<sup>28</sup> 'Order effects' refers to the influence that repeated treatment or testing may have on the same subject. It can be balanced by randomising the order in which a treatment is administered to the participants (Martin and Bateson 1993, pp. 29-30).

the presence of their human companions, as this was deemed reassuring for the cats. All the cats were observed (and fitted with the trackers) once they showed signs of sufficient confidence (e.g. rubbing their head on the observer). The experimental design was assessed and approved by the Animal Welfare Ethical Review Body (AWERB) of The Open University (Ref. N. AWERB/2016/2202/Paci/1, see Appendix 1) and conforms with the ACI research ethics protocol. Cat participation was incentivised by offering small-amount tokens to their carers, who also consented to the publication of the data acquired during the study.

### *Observed behaviour*

One of the study's aims was to investigate whether wearing a given tracking device would induce behavioural responses that could be interpreted as the result of an unpleasant experience (e.g. irritation). To this end, the specific methodological question addressed was how to identify reactions that may indicate a discomfort relatable to the device.

Although the devices tested are marketed as suitable for cats and available to purchase by any cat carer, the general hypothesis was that, when attached to the cat's body, they increase the occurrence and/or duration of certain reactive behaviours. *Reaction* is defined by The Oxford English Dictionary as the “*neural, neuromuscular, or behavioural response to a stimulus, or more generally: any response to an event; something done, felt, or thought in response to a situation or event*”. However, a working definition for this research is that of perceptual awareness by Sommerville and Broom (1998). These authors describe it as “*a perceived stimulus [that] results in an automatic response which may be modifiable, e.g. scratching to relieve irritation, or not modifiable, e.g. blinking when an object passes close to the eye*” (in Broom (2003), p. 91).

To answer the question, three behaviours that more likely could be related to the presence of a foreign object on the body of the animal were initially chosen from the cat ethogram (Stanton et al. 2015) for measuring. For example, cats may insist on grooming themselves in a particular spot in response to soil on their fur or a tick on their skin, or they may scratch because of flea infestation, or shake their body to get water off the fur. Thus, the three reactions hypothesised were: 1) grooming a spot to discard a foreign body, 2) scratching the site of attachment to attain relief, 3) shaking the head and/or body to release an object or substance from the body, or to release a cumulative neuronal stimulus<sup>29</sup> (Manning and Dawkins 1992, p. 6). These three behaviours were also found to be indicators of stress in cats by van den Bos (1998), thus they were deemed suitable for our investigation.

Furthermore, during the observations, particular responses that differed from grooming, scratching, and head/body shaking, but that the observer deemed related to the presence of

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<sup>29</sup> Manning and Dawkins (1992) explain that summation is the neuronal process by which “*neurons are able to summate excitation coming at different times (temporal summation) and from different places (spatial summation)*”. A reflex such as head/body shaking might be elicited by an irritating stimulus; weak stimuli may not evoke any response, but they can accumulate till the response occurs.

the device, were observed and therefore noted for qualitative analysis. These responses included obvious direct interactions (e.g. actual biting of the tag case) and attempts to interact with the device (e.g. movements of the head to reach the case with open mouth even if biting was not performed). For convenience, these behaviours directed towards the devices were grouped all together into a unique category named '*active interaction*'. Behaviours of this category noted by the observer were licking, biting, and cuffing the case or attachment of the device, or rolling the head and raising a paw in an attempt to lick, bite or cuff the device. The category of active interaction also accounted for behavioural individuality, whereby each cat can perform a direct action in a different way (Feaver et al. 1986).

All the base behaviours listed above are defined in Stanton's ethogram (Stanton et al. 2015):

- Scratching: cats scratch their bodies using the claws of their hind feet.
- Head/body shake: cats rotate their head/abdomen from side to side.
- Groom: cats clean themselves by licking, scratching, biting or chewing the fur on their body; this may also include the licking of a front paw and wiping it over one's head.
- Lick: cat's tongue protrudes from mouth and strokes (the device).
- Bite: cats snap teeth at and are successful in biting (the device).
- Cuff: cats strike at (the device) with forepaw and contact is made; claws are usually extended.
- Head-rolling: cats toss their heads in a circular motion (trying to reach the device).
- Raising paw: cats lift their forepaw as if to cuff, paw or strike at (the device) but do not follow through with the action.

#### *Measuring parameters: definition of bouts*

Grooming, scratching, and head/body shaking were performed by cats as single episodes, or in sequences of multiple behaviours (e.g. licking the fur for a number of seconds, scratching, shaking the head and licking again in succession). Such sequences can be interrupted for few seconds by distractive events (e.g. while a cat is grooming, he/she might be distracted by a sudden noise, thus stopping and restarting after a while). To measure behavioural parameters of each behaviour systematically in such a complex situation, single episodes and discrete behaviours of a sequence needed to be clearly distinguished and separated into bouts.

A *bout* is a repeated succession of the same brief act (in which case is called event), or a relatively prolonged activity (in which case is called state) (Martin and Bateson 1993, p.67; Dawkins 2007, p. 85). Defining a bout means establishing a clear start and end of an event

or state and it is necessary for the purpose of exactly counting the occurrences and durations of a behaviour.

In this study, grooming was accounted for as a state since it is usually a prolonged activity, while scratching and head/body shaking episodes were considered events since they are usually characterised by relatively short durations. For each category of behaviour, bouts were defined as follow:

A simple grooming bout was when the cat groomed their fur continuously without interruptions (in other words, when the typical movement of the head as the cat protrudes the tongue for licking was not interrupted). However, grooming sequences can be more complex. In such cases, the cat can stop grooming to change position, or to just pause, or to pay attention to a distraction, to then come back to grooming after a while. In this analysis, any change in behaviour was considered as an interruption of the bout (e.g. grooming stops when the cat jumps on a stool), except for changes in position made for grooming purposes (e.g. grooming momentarily stops when the cat reposition *himself* from standing to sitting to groom the belly), or when staring at something that caught the cat's attention (e.g. a sudden noise). When one of these two exceptions applied, a pause of less than 30 seconds was included within the grooming bout, but an interruption of 30 seconds or more was considered a change in behaviour and defined the end of the bout. This lapse was deemed by the observer long enough to mark a change in behaviour rather than a momentary interruption due to environmental distractions. The duration of grooming was recorded net from the pauses or sudden distractions, that is the chronometer used for recording durations was stopped during momentary interruptions but restarted immediately as the cat resumed grooming (thus considering the action as one occurrence). For example, if during grooming the cat stopped to stare at something but resumed grooming within 30 seconds, the behaviour was considered as a single occurrence and clocked for the effective time during which the stroking movement of the tongue was performed.

Scratching is a distinctive behaviour composed by repeated and rapid movements of a cat's hind leg that strikes a body part. The set of these limb movements defines the duration of a scratching episode. A scratching occurrence was counted only when participants scratched their neck or throat (i.e. where the device was placed) using the claws of their hind feet continuously without stopping. The bout started when cats rose up the scratching foot and ended when they put the foot on the ground. If the cat restarted after this, it was considered as a new occurrence. This was because scratching is better defined as an event and as such it can be approximated as a point in time (Martin and Bateson 1993, p. 66).

Head and body shaking were deemed related behaviours that measure the same reaction. Thus, they were considered a single category (Martin and Bateson 1993, p. 58). A head or body shaking bout consisted of various rapid side-to-side rotations of the head or abdomen. The movements are so rapid that it is clearly distinguishable when a shaking episode starts

and stops. Head and body shaking were not counted when clearly performed because of other stimuli (e.g. when some long-haired participants shook their heads during grooming to tear off hair knots more efficiently).

### **5.3 Data analysis**

All observational sessions were video-recorded, and all the videos were analysed with the aims of detecting and measuring behaviours that might indicate a discomfort resulting from the presence of the device and of identifying design flaws related with wearability that needed a redesign. Video aid was utilized in order to record more than one behaviour at once in complex sequences where the participants were performing multiple behaviours in a row (Dawkins 2007, pp. 85, 142). Video aid was fundamental for the exact measurement of behavioural parameters and for the capture of singular behaviours (*incidents*) which could then be analysed qualitatively.

#### **5.3.1 Measurement of behaviours**

Following the definitions of bout described above, a quantitative analysis consisted of counting how many times cats performed each of three pre-selected behaviours (i.e. grooming, scratching, and head/body shaking) throughout the whole registration period and for how long each episode of grooming and scratching lasted. Device and control treatments were compared to see whether measurements differed across conditions. The aim of this analysis was to ascertain whether the pre-selected behaviours may have been triggered by the wearables, and therefore constitute indicators of negative impact; or whether, being similarly frequent and lasting across the three conditions, they could be discarded as customary or context-induced behaviours (for example, a constant influence due to the presence of the observer).

We counted frequencies (intended as number of occurrences) and measured the duration of each occurrence when relevant (i.e. in grooming and scratching) following an all-occurrence sampling (section 3.4.3). For scratching, the behaviour was counted only when directed at the collar region. For head/body shaking, incomplete rotations, that is when started but stopped with a rotation only to one side instead of side to side, were counted as half occurrences. Shaking duration was not registered because clocking the rapid rotation of the head and/or body was deemed too detailed a peripheral measure for the purpose of this study, not providing useful information about discomfort beyond the increment of its frequency (Dawkins 2007, p. 85).

#### *Statistical analysis*

A statistical analysis was conducted to ascertain whether frequency and duration of the cats' reactions increased with significance across conditions. Nonparametric Friedman's two-way ANOVA for repeated measures design (Lehner 1998, p. 434) was adopted to test differences within frequencies in grooming, scratching, and head/body shaking behaviours,

and durations in grooming and scratching. Where a statistical significance was found, a Wilcoxon signed-ranks test (Lehner 1998, p. 423) was used to identify where the differences were.

Within this study, frequency data are counts of behavioural events. Due to their non-numerical nature, they never follow a normal distribution, but a Poisson distribution instead (Grafen and Hails 2002, p. 258). The basis for statistical analysis is that if data are not normally distributed, parametric tests cannot be employed (Grafen and Hails 2002, p. 136). Hence, for frequencies, the use of nonparametric tests was deemed appropriate. Conversely, durations are counts of actual numbers (e.g. seconds or minutes) which can potentially be distributed normally, especially when the sample size is large enough (more than 30 measurements) to be in accordance with the central limit theorem of statistics<sup>30</sup> (Upton and Cook 2008). However, the sample size in this study was small ( $N = 13$ ), and even if normality had been met, there would have been a higher possibility of a type 1 error occurring (i.e. rejecting the null hypothesis when it is actually true (Grafen and Hails 2002, p. 325)). Thus, nonparametric statistics were also used for durations.

The p-value was selected as  $p < 0.05$ , which is conventional in ethological studies (Lehner 1998, p. 325). It was hypothesised that grooming, scratching and head/body shaking would increase with the presence of the devices (PawTrax and Tractive). In particular, as the Tractive is bulkier than the PawTrax, we hypothesised that the former would impinge more than the latter, in accordance with studies that reports how the device weight affects behaviour and movements of domestic cats (Coughlin and van Heezik 2015). Thus, the alternative hypothesis was directional (which implies the use of one-tailed statistical tests), with  $H_1$ : Control (C) < PawTrax (P) < Tractive (T). The software IBM SPSS Statistics Version 21.0 was used for the analysis<sup>31</sup>.

### 5.3.2 Description of behaviours

During the device conditions, explicit behaviours aimed or seemingly directed at the device (i.e. active interactions), which were different from grooming, scratching, and head/body shaking, were annotated. These behaviours were cats' singular and individual acts that were not foreseen before the study, in which the cats bit or licked or tried to bite the device, rolled their heads (i.e. tossing the head in circular motion as described in the ethogram (Stanton et al. 2015)) to investigate what was on their neck, cuffed the tag with their forepaws, and struck a forepaw in a motion directed at the collar region. Due to their singularity, active

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<sup>30</sup> From Upton and Cook (2008): The central limit theorem states that, for large  $n$ , the distribution of  $\bar{X}$  is approximately a normal distribution with mean  $\mu$  and variance  $1/n\sigma^2$ . Thus, for a large random sample of observations from a distribution with mean  $\mu$  and variance  $\sigma^2$ , the distribution of the sample mean is approximately normal with mean  $\mu$  and variance  $1/n\sigma^2$  and the distribution of the sample total is approximately normal with mean  $n\mu$  and variance  $n\sigma^2$ .

<sup>31</sup> IBM Corporation. Released 2012 IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY.

interactions were described and analysed qualitatively as incidents, that is recognising them as clear acts of discomfort (section 3.4.3).

Likewise, while watching the video recordings, we noted that the four categories of behaviours (i.e. grooming, scratching, head/body shaking, and active interactions) were sometimes performed in aggregated patterns (e.g. a cat shaking the head twice, then licking the case of the tag, and scratching immediately after). As a whole, they were interpreted as being reactions due to the overstimulation from the device. Hence, such video strings were selected and systematically described, using a cat ethogram (Stanton et al. 2015) as a species-specific objective descriptive tool. Additionally, environmental, contextual, and species or breed-specific factors linked to the presence of the device were noted down too; these included: interactions with other animals of the household, species/breed-specific behavioural and morphological characteristics of the cats (i.e. sniffing and rubbing behaviour, length of the fur), or environmental features (e.g. kind of walking surface, access to a garden, etc.). Active interactions, aggregated patterns, and environmental/contextual/breed-specific factors were analysed qualitatively both to show the extent of discomfort experienced by some individuals, and to understand what feature of a device might have produced a negative experience and might need to be redesigned.

#### *Descriptive process*

Video sequences showing active interactions and behaviour of interest performed in aggregated patterns were described and such descriptions were transcribed. The process consisted of breaking down the cats' activities of each incident into discrete behavioural components and assigning qualifiers to them as appropriate. For example, a sequence might have shown a cat who scratched the neck, shook his body, walked few steps, stopped and licked the collar region, then scratched his body again. The vocabulary used for species-specific descriptions complied with the ethogram's terminology as much as possible, but when qualifiers were used to describe the quality of reactions, they were in accordance with the observer's frame of reference. Such observer's subjectivity (called *observer effect* in ethological research (Lehner 1998, p. 211)) was systematised by defining each qualifier the first time it was used and using the qualifier according to its definition henceforth. For example, the description 'the cat shook his body twice consecutively' referred to the specific cat's base behaviour of rotating the abdomen from side to side as stated in the ethogram (Stanton et al. 2015), with the addition of the qualifier 'consecutively', which was defined as double or multiple shaking events in continuous repetition. In the same way, 'the cat shook her body repeatedly three times' referred to the same base behaviour, but in this case the qualifier 'repeatedly' was assigned in the case of double or multiple shaking events performed repeatedly during the observed series but not continuously, that is interspersed with other behaviours (e.g. scratching).



Using this systematic technique, transcribed reactions for each sequence were appropriately sorted into ‘topic nodes’ using the software QSR International’s NVivo version 11<sup>32</sup>. Within this application, the coding of nodes (i.e. gathering converging material into one descriptive container) is a dynamic process during which the meaning and structure of the nodes may be modified over time. At any time, nodes can be generated, merged, aggregated, separated, sub-grouped, etc. For the data analysis of this study, coding was done both by placing each transcribed reaction into previously created nodes and by creating new nodes as appropriate while examining the transcriptions. Initially, nodes corresponded to the three behaviours of grooming, scratching, and head/body shaking, since these were pre-selected as potential indicators of discomfort. Progressively, the nodes were modified and sub-grouped in hierarchies as, and when, pertinent qualities of each behaviour were found (nodes called ‘parent’ might thus contain new sub-groups called ‘child nodes’). For example, head/body shaking descriptions were placed into the node accordingly named ‘shaking’. When a particular trait of shaking was found in the text (as in one of the previous examples: ‘the cat shook his body twice consecutively’) a child node, called ‘head/body shaking - consecutively’ was created to ‘collect’ the descriptions of shaking corresponding to the study-specific definition of ‘consecutive’. The same was done for the ‘head body shaking - repeatedly’ child node, and so on. Every time a reaction found in the transcriptions of the videos was the same or highly resembling a behaviour already coded, it was included into an already existing node. On the other hand, when a relevant behaviour differing from those already coded was described, a new code and corresponding new node was generated, and the node became a new container for the same kind of information. In this way, any active interaction and aggregated pattern, as well as ambient features, individual habits, and morphological characteristics related to wearing a device were systematically identified.

This procedure resulted in a broad range of cat behavioural patterns, described in the findings section (5.4). Descriptions of behaviours served particularly to investigate which features of the two devices might have provoked a reaction and therefore to assist in appraising potential wearability flaws in the devices. Ultimately, the aim of this analysis was to look for device flaws and, from these, establish design requirements to inform the design of wearer-centred devices that would afford improved wearability.

## **5.4 Findings**

This section is organised by behaviours detected. For each of them, the quantitative and statistical results are reported first, and then salient video sequences showing active interactions and aggregated patterns of behaviours (incidents) are described. Table 5.2 and Table 5.3 summarise the descriptive statistics for frequencies and mean duration for grooming, scratching and head/body shaking under different experimental conditions.

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<sup>32</sup> QSR International Pty Ltd. Version 11 (2016) NVIVO qualitative data analysis software.

	Control groom frequen	PawTrax groom frequen	Tractive groom frequen	Control scratch frequen	PawTrax scratch frequen	Tractive scratch frequen	Control shaking frequen	PawTrax shaking frequen	Tractive shaking frequen
Mean	4.15	3.62	4.69	.54	4.92	4.00	3.53	9.88	8.50
Median	4.00	2.00	3.00	1.00	1.00	2.00	3.50	11.00	8.00
Std. Deviation	2.85	4.73	4.67	.51	6.44	5.91	2.61	7.37	6.60

Table 5.2: Descriptive statistics (mean, median, standard deviation) for frequency.

	Control groom mean duration	PawTrax groom mean duration	Tractive groom mean duration	Control scratch mean duration	PawTrax scratch mean duration	Tractive scratch mean duration
Mean	43.33	30.05	38.50	2.82	2.62	3.99
Median	20.72	17.52	12.27	3.61	2.80	4.25
Std. Deviation	41.41	32.35	62.30	3.05	2.81	3.42

Table 5.3: Descriptive statistics (mean, median, standard deviation) for mean duration in seconds.

In the result Tables 5.4, 5.6, and 5.8, the behavioural occurrences between experimental conditions are indicated as ‘equal’ (‘=’, if the difference is zero), ‘similar’ (‘≈’, if the difference is more than zero but no more than three) or ‘more/less’ (‘>’ / ‘<’, if the difference is more than three).

#### 5.4.1 Grooming

The statistics for grooming are as follow. Means for frequencies in the three experimental conditions were 4.15 (s.d. = 2.85) during control, 3.62 (s.d. = 4.73) with PawTrax, and 4.69 (s.d. = 4.67) with Tractive. Medians were 4.00 for control, 2.00 with PawTrax, and 3.00 with Tractive (Table 5.2).

Means for (mean) durations in seconds were 43.33 (s.d. = 41.41) during control, 30.05 (s.d. = 32.35) with PawTrax, and 38.50 (s.d. = 62.30) with Tractive. Medians were 20.72 for control, 17.52 with PawTrax, and 12.27 with Tractive (Table 5.3).

Table 5.4 illustrates the number of occurrences and mean durations registered for each cat. Grooming frequency was equal or similar (from 0 to 3 occurrences) across the three conditions in C2, C5 and C9 (three cats). Five participants (C1, C8, C11, C12, and C13) had higher frequencies during control than both PawTrax and Tractive. C3 and C4 (two cats) groomed more frequently (> 3 occurrences) with PawTrax, but with control and Tractive the behaviour remained equal or similar. On the contrary, C6, C7, and C10 (three cats) groomed more frequently with Tractive, while with PawTrax and control the behaviour remained similar. These results do not show the trend hypothesised, according to which ‘during-control’ grooming would be less frequent than ‘during-device’ grooming. Statistical analysis showed that there was no statistically significant difference in grooming frequencies across the three conditions, as tested with the Friedman’s test, with  $X^2(2) = 3.061$ ,  $p = 0.216$  ( $p > 0.05$ ). Duration did not show any trend and did not give statistically significant difference across conditions either, with  $X^2(2) = 1.440$ ,  $p = 0.487$  ( $p > 0.05$ ).

Hence, grooming was discarded as a potential indicator of discomfort and no further analysed.

Cat ID	Grooming n. of occurrences					Grooming mean duration (sec.)				
	P		C		T	P		C		T
C1	1	<	7	>	4	11.92	<	20.67	<	76.53
C2	1	≈	2	≈	3	2	<	122.35	>	19.82
C3	12	>	2	=	2	17.53	>	1.14	<	12.27
C4	14	>	5	≈	7	50.37	>	9.03	<	9.5
C5	0	=	0	=	0	0	=	0	=	0
C6	0	≈	1	<	12	0	<	20.72	>	5.72
C7	8	≈	6	<	15	62.53	<	72.7	>	21.47
C8	2	<	8	>	5	59.95	>	94.15	>	54.2
C9	0	≈	1	≈	2	0	<	2.27	<	2.71
C10	4	≈	2	<	8	27.03	>	7.78	<	73.54
C11	2	<	6	>	3	66.05	<	68.65	<	224.77
C12	3	≈	4	>	0	93.37	>	80.63	>	0
C13	0	<	9	>	0	0	<	60.36	>	0

Table 5.4: Number of grooming occurrences and durations for each cat. *P* stands for PawTrax, *C* for control and *T* for Tractive. ‘=’ and ‘≈’ indicate (respectively) equal or similar values (within 3 occurrences); ‘<’ and ‘>’ indicates a difference of more than 3 occurrences.

Consistent with the statistical findings, the analysis of prolonged grooming (that is, when cats lick throughout their bodies) shows that this behaviour was performed in a relatively similar way among the three conditions. However, events of single or few repetitive licking exclusively directed at the collar region (neck and throat) were detected during the video analysis. These constituted uncharacteristic reactions, such as actual strokes on the collar and/or case with the tongue, and deep bends of the neck and protrusion of the tongue indicating attempts to reach the device attachment area, even when contact with the case or collar was not made.

Selected video sequences of active interactions and aggregated patterns which included licking events showed that some cats physically licked the Tractive case. As a consequence, the regular tongue movements of the grooming action were disrupted by the obstruction of the device (i.e. C1, and C6). For example, after his tongue made contact with the case, C1 stopped licking and immediately pulled his head back, retracting and protruding his tongue in the air, and contracting his neck muscles. Then, he tried to lick his throat but did not succeed because the hard case (positioned on the throat) was in the way, impeding the neck from normally bending forward. This was evident from the double nodding movement of the head immediately followed by an insistent scratching of the throat that lasted around 7

seconds<sup>33</sup>. C6 provided another example of interaction between the tongue and the case. In this instance, C6's abrasive tongue rasped the case, remaining stuck to it and briefly stretching, thus provoking a grimace. In some of the other cats, the contact the tongue made with the case directly triggered more conspicuous reactions (i.e. C7, and C10). The examples of C7 and C10 are emblematic. While licking his throat, C7 suddenly touched the case with his tongue. This triggered an immediate reaction against the case, whereby the cat first rolled the head as if looking at the foreign body perceived through the tongue, and then grasped the case with both forepaws while opening and shutting his mouth, clearly attempting to bite the case. The same happened with C10, who started with licking the collar on the neck, pulling rigidly his head backwards and bending his neck forward. Then, he rolled the head and stroked the case with the tongue. The case initially impeded the movement of the neck forward (as it happened with C1). In order to reach the unreachable spot on the throat, C10 contracted his body and repeatedly licked the neck on either side of the case with single strokes each side. These tongue strokes around the collar zone, suddenly performed, in some cases alternatively switching from one side of the neck to the other, for the observer indicated a reaction against the device. C7, C10, and C11 repeatedly seemed to direct such single strokes to the collar during the Tractive condition.

In contrast to Tractive, the PawTrax case was never licked directly. This is consistent with the fact that the PawTrax collar is slimmer than its counterpart, visually and spatially less conspicuous, and less easy to target. However, C7 repeatedly turned his head alternately licking the region near the collar on either side, making the same head movements consisting of turns, tosses and shakes indicating discomfort, as if reacting to a stimulus on the body.

From the video sequences described above, two licking patterns were deemed worthy of consideration for evaluating the wearability of the devices. These are described in Table 5.5.

Licking behaviour	PawTrax	Tractive
i) licking or trying to lick the collar (licking the collar area with single strokes)	C7	C4, C6, C7, C10, C11
ii) licking the case	-	C1, C6, C7, C10

*Table 5.5: List of licking qualities performed by the participants.*

### 5.4.2 Scratching

Descriptive statistics for scratching are as follows. Means for frequencies in the three experimental conditions were 0.54 (s.d. = 0.51) during the control, 4.92 (s.d. = 6.44) with the PawTrax, and 4.00 (s.d. = 5.91) with the Tractive. Medians were 1.00 for control, 1.00 with the PawTrax, and 2.00 with the Tractive (Table 5.2).

<sup>33</sup> Albeit a qualitative analysis, when the observer deemed a scratching act to be 'insistent', its duration was registered in order to systematise the use of the adjective. When longer than 6 seconds, scratching was qualified as insistent.

Means for scratching (mean) durations were 2.82 (s.d. = 3.05) during control, 2.62 (s.d. = 2.81) with PawTrax, and 3.99 (s.d. = 3.42) with Tractive. Medians were 3.61 for control, 2.80 with PawTrax, and 4.25 with Tractive (Table 5.3).

Frequency and duration data for each cat are illustrated in Table 5.6. Scratching frequencies during the control condition were very low for all 13 cats (they never scratched or did it once). Six participants reacted by scratching more frequently ( $> 3$  occurrences) to either one or both devices. In particular, four cats incremented scratching occurrences with both devices (C4, C7, C9, and C10). Two other participants increased scratching with only one of the two devices: namely the PawTrax (but not the Tractive) for C3, and the Tractive (but not the PawTrax) for C6. The other seven cats did not show a difference greater than 3 occurrences between conditions. Although four cats showed a noticeable increment in scratching with both devices, Friedman's test results showed that there was no statistically significant difference in scratching frequency across the three different conditions, with  $X^2(2) = 2.837$ ,  $p = 0.242$  ( $p > 0.05$ ). Neither did the difference in mean duration give statistical significance, with  $X^2(2) = 0.311$ ,  $p = 0.856$  ( $p > 0.05$ ).

Cat ID	Scratching n. of occurrences					Scratching mean duration (sec.)				
	P		C		T	P		C		T
C1	0	≈	1	≈	2	0	<	3.94	<	5.98
C2	0	≈	1	=	1	0	<	9.15	>	2.5
C3	12	>	1	≈	0	2.94	<	3.61	>	0
C4	9	>	1	<	21	5.5	>	4.71	<	5.13
C5	0	=	0	=	0	0	=	0	=	0
C6	0	=	0	<	4	0	=	0	<	8.04
C7	8	>	0	<	6	5.3	>	0	<	3.15
C8	2	≈	1	≈	0	7.82	>	3.74	>	0
C9	14	>	0	<	10	4.42	>	0	<	4.25
C10	18	>	1	<	5	5.41	<	6.2	>	5.4
C11	0	≈	1	=	1	0	<	5.33	<	7.17
C12	0	=	0	≈	2	0	=	0	<	10.37
C13	1	≈	0	=	0	2.8	>	0	=	0

Table 5.6: Number of scratching occurrences and durations for each cat. P stands for PawTrax, C for control and T for Tractive. '≈' and '≈' indicate (respectively) equal or similar values (within 3 occurrences); '<' and '>' indicates a difference of more than 3 occurrences.

Based on these results, scratching duration was discarded as a parameter to be considered. However, scratching frequency was further analysed since the four individuals who showed an important increment in respect to the control (i.e. C4, C7, C9, and C10) also exhibited

scratching patterns and other behaviour which suggested discomfort caused by the devices and which pointed to device feature that could have provoked such reactions.

Video strings of scratching episodes treated as aggregated patterns sequences by the observer were analysed in the case of C3, C4, C7, C8, C9, C10, and C12 with PawTrax; and in the case of C4, C6, C9, and C10 with Tractive. Table 5.7 summarises the scratching qualities deemed important for the wearability analysis of the devices.

Scratching behaviour	PawTrax	Tractive
i) double scratching on the same spot of the neck/throat performed repeatedly	C3, C4, C7, C9, C10	C4, C9, C10
ii) scratching insistently (i.e. for more than 6 seconds)	C3, C4, C7, C8, C9, C10, C12	C1, C4, C6, C10, C12
iii) repeated scratching performed in alternation on both sides of the neck	C4, C7, C8, C9, C10	-
iv) scratching the case or collar of the device	C3, C4, C9, C10	C1, C4, C6, C10, C11
v) scratching where the buckle is	-	C4, C6, C9

*Table 5.7: List of scratching qualities performed by the participants.*

For PawTrax, four categories were found (Table 5.7): i) double scratching on the same spot of the neck/throat performed repeatedly (by five cats: C3, C4, C7, C9, and C10); ii) insistent scratching (i.e. for more than 6 seconds) (by seven cats: C3, C4, C7, C8, C9, C10, and C12); iii) repeated scratching performed in alternation on both sides of the neck (by five cats: C4, C7, C8, C9, and C10); and iv) scratching directly the case or the collar of the device (by four cats: C3, C4, C9, and C10).

A salient incidence analysed was for example the case of C4 with PawTrax, who scratched the case insistently (for 9 seconds), shook his body, and then resumed scratching for 8 more seconds the case on the other side of his neck (evidence of the contact between the claws and the case was given by the hitting noise produced every time one of the hind feet hit the device). The scratching behaviour of C7 with PawTrax is also indicative; one of the videos showed that the participant scratched the same spot of the neck various times during a short time sequence lasting little longer than a minute. From the video's audio, it was clear that the cat was scratching the collar instead of the skin underneath, as evident from the sound generated by the claws hitting the collar. Similarly, C9 scratched the same spot on the neck various times during a very short period (of 30 seconds). In one episode, both C9 and C7 respectively, also scratched one side of the neck and the other side immediately afterwards. C4 and C10 did the same thing during the recordings with PawTrax. In particular, C10 was the protagonist of a highly relevant sequence: the cat was crouching when he suddenly sat and scratched his throat; then he licked the right hind foot he had used for scratching and resumed scratching the same right spot, next to the edge of the case; then, he again licked the same hind foot used for scratching and shook his head; afterwards, he shook his body,

stopped for a few seconds sniffing around, but then resumed scratching the same spot and did so twice; he then stopped, groomed for a few seconds, and scratched insistently (for 11 seconds) his throat on the left side, again next to the edge of the case. Interestingly, the case did not slide around the neck in spite of the force exerted by the striking leg, but instead remained firmly in the same position. When he stopped scratching, the cat licked the same hind left foot used to scratch and then shook his head. At this point, he was sitting, looking around, when he started scratching again the same left spot exactly where the case was; this was another long scratching session (14 seconds) during which the case remained firmly in position; then the cat stopped scratching the left side, turned and immediately restarted scratching the right side.

For Tractive, the categories found (Table 5.7) were: i) double scratching on the same spot performed repeatedly, found with three cats (C4, C9, and C10); ii) scratching insistently (i.e. for more than 6 seconds), found in five cats (C1, C4, C6, C10, C12); iv) scratching the case or collar, found in five cats (C1, C4, C6, C10, and C11); and v) scratching the spot where the buckle is. However, scratching repeatedly on both sides of the neck (category iii) was never performed with the Tractive.

A noteworthy scratching behaviour of C4, C6, and C9 regarded the nape of the neck, which is where the buckle of the collar holding the Tractive device was positioned. In particular, C4 scratched his nape while wearing the Tractive during various episodes. On one occasion, C4 started scratching the right side of the neck, moving on to scratching the nape; then, he stiffly tilted the head back while stretching the neck upwards and froze for an instant in this rigid position; he then released the position, slightly rolling the head and licking the left side of the neck with a stroke; immediately afterwards he scratched again the nape but this time he did so with the left hind foot. In comparison, the same cat (C4) scratched the nape in one sequence twice for couple of seconds each time during PawTrax (whose collar does not have a buckle). C6 never scratched the nape with PawTrax but did so insistently with Tractive. Similarly, C9 never scratched her nape during PawTrax but did so during Tractive.

### **5.4.3 Head/body shaking**

Descriptive statistics for head/body shaking are as follow. Means for frequencies under the three experimental conditions were 3.53 (s.d. = 2.61) during control, 9.88 (s.d. = 7.37) with PawTrax, and 8.50 (s.d. = 6.60) with Tractive. Medians were 3.50 for control, 11.00 with PawTrax, and 8.00 with Tractive (Table 5.2).

Data in Table 5.8 shows that six cats had a more-than-three-occurrences increment in head/body shaking with both devices in comparison with the control condition (i.e. C4, C6, C7, C9, C10, and C11). For C3 and C13 there was an increment ( $> 3$  occurrences) with PawTrax but not with Tractive, while for C12 there was an increment with Tractive but not with PawTrax. Three cats (C1, C5, and C8) exhibited similar frequencies of shaking under all three conditions. C2 shook his head/body more during control. The statistical analysis

with Friedman's test showed that there was a significant difference in head and body shaking frequency across the three different conditions, with  $X^2(2) = 6.533$ ,  $p = 0.038$  ( $p < 0.05$ ).

A further post-hoc analysis with Wilcoxon signed-ranks test was then performed to see where the significant differences were. In order to do so, it was necessary to use the Bonferroni adjustment to the p-value (Grafen and Hails 2002). Comparisons of interest were Control\*PawTrax, Control\*Tractive, and PawTrax\*Tractive. Bonferroni was calculated taking the level of significance used in the previous Friedman's test (i.e. p-value = 0.05), and dividing it by 3 (i.e. number of conditions in the experimental design). Hence:

$$\text{Bonferroni adjustment} = 0.05/3 = 0.0166$$

This means that outputs from Wilcoxon must be compared with the Bonferroni adjustment. Significance outputs bigger than the Bonferroni adjustment ( $p > 0.0166$ ) mean that the outputs are not statistically significant (that is, there is no significant difference between coupled conditions).

For head/body shaking, Wilcoxon (one-tailed) showed statistical significance between PawTrax and control, with  $Z = -2.244$ ,  $p = 0.0125$  ( $p < 0.0166$ ), and Tractive and control, with  $Z = -2.15$ ,  $p = 0.0155$  ( $p < 0.0166$ ). There was no significant difference between PawTrax and Tractive, with  $Z = -0.445$ ,  $p = 0.328$  ( $p > 0.0166$ ).

Cat ID	Shaking n. of occurrences				
	P		C		T
C1	2	=	2	≈	4
C2	1	<	10	>	0
C3	11	>	3	≈	3.5
C4	20	>	4.5	<	12
C5	0	=	0	=	0
C6	5.5	>	0	<	8
C7	12.5	>	3.5	<	21
C8	3	≈	5	≈	4
C9	15	>	2.5	<	14
C10	18	>	2	<	18
C11	14	>	3.5	<	9
C12	6	=	6	<	12
C13	20.5	>	4	≈	5

Table 5.8: Number of head/body shaking occurrences for each cat. P stands for PawTrax, C for control and T for Tractive. '=' and '≈' indicate (respectively) equal or similar values (within 3 occurrences); '<' and '>' indicates a difference of more than 3 occurrences.



From video sequences, four head and body shaking patterns were found. These are summarised in Table 5.9. They were: i) shaking consecutively (i.e. in continuous repetition), ii) forcefully (i.e. cats losing their balance), iii) repeatedly (i.e. interspersed with other reactions), and iv) while walking.

In particular, for PawTrax, four cats shook their heads or bodies consecutively (C3, C7, C11, and C13), four did it forcefully losing their balance (C3, C10, C11, and C13), five did it repeatedly (C4, C7, C9, C10, and C13), and four cats shook suddenly while walking (C7, C9, C11, and C13).

For Tractive, three cats shook consecutively their heads or bodies (C9, C11, and C12), four did it forcefully (C10, C11, C12, and C13), four did it repeatedly (C7, C9, C10, and C12), and only one shook suddenly while walking (C7).

For example, while wearing Tractive, C12 shook her head twice in a row, and then re-shook it after 10 seconds. This accounted for both consecutive and repeated shaking. In another occasion, she shook her body so forcefully that she lost her balance and nearly fell on her side.

Shaking behaviour	PawTrax	Tractive
i) shaking - consecutively	C3, C7, C11, C13	C9, C11, C12
ii) shaking - forcefully	C3, C10, C11, C13	C10, C11, C12, C13
iii) shaking - repeatedly	C4, C7, C9, C10, C13	C7, C9, C10, C12
v) shaking - while walking	C7, C9, C11, C13	C7

*Table 5.9: List of shaking patterns performed by the participants.*

#### **5.4.4 Active interaction**

As discussed previously, seven behaviours identified as active interaction were extrapolated from video analysis (i.e. actual licking of the case, actual biting of the case, attempting to bite the case, licking the collar area, head rolling, cuffing the case with forepaws while standing on hind legs, attempting to strike the collar region with a forepaw (Table 5.10)). Although they were described and listed as distinct, these behaviours were grouped together in the same category since, in the observer's opinion, their manifestation indicated a reaction undoubtedly caused by the device. Such active interactions were sometimes performed in conjunction with - after, before or in between - licking, scratching and shaking behaviours; other times they were triggered by environmental elements or species-specific behaviours, such as rubbing the neck - and therefore the device - on objects or on the floor.

Table 5.10 summarises which interactive behaviours were performed by each individual and with which device. Seven cats (C1, C4, C6, C7, C10, C11, and C13) had an active interaction with at least one of the devices. More specifically, C13 interacted with the PawTrax (but not the Tractive) by attempting to strike the device with her paws several times. C7 reacted to both devices by licking the collar area repeatedly when wearing both PawTrax and Tractive,

and by biting and cuffing the case of Tractive. In this last event, the cat reared on his hind limbs while cuffing the device with his forepaws. He also rolled his head in various occasions while wearing Tractive. The other five cats interacted with Tractive only. Specifically, C4, C6, and C10 bit or attempted to bite the Tractive case and rolled their heads as if looking around. C6 also reared on hind legs and cuffed the case with forepaws similarly to C7. In addition, C1, C6, and C10 licked the Tractive case, while C4, C6, C7, C10, and C11 licked the collar and around the collar area.

Cat ID	Active Interaction behaviours per each cat
C1	Tractive: actual lick of the case
C4	Tractive: attempt to bite the case, head rolling, licking the collar area
C6	Tractive: attempt to bite the case, actual bite of the case, head rolling, cuffing the case with forepaws while standing on hind legs, actual lick of the case, licking the collar area
C7	PawTrax: licking the collar area Tractive: actual lick of the case, actual bite of the case, head rolling, cuffing the case with forepaws while standing on hind legs, licking the collar area
C10	Tractive: attempt to bite the case, actual bite of the case, head rolling, actual lick of the case, licking the collar area
C11	Tractive: licking the collar area
C13	Tractive: attempt to strike a forepaw at the collar region

*Table 5.10: Kind of active interaction behaviour performed by seven of the overall participants.*

Behavioural sequences of clear hostility against the device were observed in C6, C7, and C10 when these cats wore Tractive. For example, in C6's case, after he scratched his neck, the case slid from the throat to one side of the neck. This may have triggered C6's subsequent sudden response, who stiffened and pulled back his body, rolled his head and opened his mouth snap-biting at the case. The cat could not reach the case in this instance, but immediately afterwards he raised his forepaws in rapid succession, reared on his hind legs and tried to cuff the case. From this standing position, he carried on opening and shutting his mouth in an attempt to bite the case. In another of these episodes (there are a total of 8 biting sequences and 3 cuffing strings in C6), this participant shook his head while side-lying on the carpeted floor, he then stretched his body and forepaws and suddenly reached for his throat with his forepaws, while opening and shutting his mouth, snapping at and biting the case. The same cat also showed consecutive rolling of the head in various occasions, as if attempting to see what was attached to his neck.

C7 and C10 had similar interactions with Tractive. On one occasion, while lounging in the garden, C7 licked his neck and throat, stopping for a while before resuming and walking away; then he rubbed the neck on the floor and lied down, stretching his body and rolling, rubbing his neck against the garden's tiled floor for few seconds. Then he shook his head and immediately afterwards he suddenly tossed his body around and stiffly tilted the head toward his throat, freezing in this position for an instant. Suddenly, while rolling on the floor, he made a jerking and agitated movement, tilting the head and trying to bite and fight against the case, which was positioned on the throat. Then he stopped and licked his paw, then suddenly rolled his head, pulled the neck backwards and, while licking his throat next

to the case, he suddenly touched it with his tongue (see the grooming section 5.4.1). At this point, he rolled his head and started cuffing and biting the case. He did this on the floor, and then he reared up standing upright with his forepaws clutched onto the case. Then he rotated his head trying to reach the nape, twitching his head and contracting his neck muscles in this position for an instant. Then, he shook his head again and grasped again the case with both forepaws in a standing position for an instant. He then stopped, distracted by a noise. After a while, he licked again his back with a sudden movement, shook his head, and licked his throat. He did this repeatedly, when suddenly he reared again standing on his hind limbs and clutching both forepaws onto the case, trying to bite it.

PawTrax did not generate the conspicuous reactions described above. For example, its case was never cuffed or licked directly. However, C7 showed a repetitive single-stroke alternation of liking each side of the neck, which points to a collar-induced stimulus, and C13 raised one of her paws and simultaneously twitched her neck repeatedly while walking.

#### 5.4.5 Environmental, contextual, and species/breed-specific factors

During the video analysis, other species or breed-specific behaviours and characteristics of cats were observed and deemed important for appraising potential wearability flaws. These were related to the cats' environmental context, specifically aspects of the domestic habitat as well as the condition of 'wearing-a-device'. These included sniffing objects, rolling the body on the floor, rubbing the head and body against objects, the floor, or other individuals (Table 5.11). Although these are typical behaviours of cats, they were noted because of the potential implications for design they might have. For example, C6 was repeatedly sniffing the air and the carpeted floor during the whole observational period (control included). This highlighted the importance that scent, and ambient odours have in the cat's life, and it suggests the need to carefully consider the use of materials, particularly those that may produce strong odours.

Environmental, contextual, and species/breed-specific factors	PawTrax	Tractive
i) sniffing objects	C6, C10	C6, C10
ii) rolling the body on the floor	C7	C6, C7, C10
iii) rubbing against objects, floor, others	-	C4, C6, C7, C10, C11, C13

*Table 5.11: List of species/breed-specific behaviours performed by the participants.*

Among the behaviours listed in Table 5.11, the most noteworthy episodes involved C7 and C10. Both cats rolled their body and rubbed their necks on tiled and wooden floors respectively while wearing the Tractive. The impact of the device on the hard floor produced a noise, suddenly followed by active interaction behaviours. In particular, C7 tossed his body lying on his belly and rigidly tilted his head toward his throat freezing for an instant; jerking and agitated movements followed that culminated with the cat rearing on his hind limbs, clutching the case with his forepaws and biting it. In another instance, from a standing

position, C10 flopped on his shoulders, bumping his neck onto the floor; upon hitting the wooden floor, the case produced a loud noise and immediately C10 jerked his head while rolling on his back; he rolled his body side to side twice, while rubbing his neck onto the floor, thus causing the case to hit the ground. C10 carried on rolling his body on the floor several other times, twisting and turning the neck and shoulders more markedly each time. With the last body rolls of the series, he also jerked and shook his head, which caused the case to again produce a loud noise against the wooden floor. At this point, he momentarily rested on one side, then suddenly opened and shut his mouth protruding the tongue and trying to bite the case. He stopped for a couple of seconds, then he rolled his body side to side again, twisting and jerking his head, attempting to bite the device again. However, since the device was on the nape, he could not reach it, so he licked the collar instead. Towards the end of the sequence, at short intervals, he rolled his body again a few times causing the case producing the same noise, before finally standing up and shaking his body.

## **5.5 Discussion**

The findings reported above clearly show that both tracking devices evaluated in the study elicited a range of reactions in the feline participants. In particular, this section discusses the findings in relation to two specific objectives: 1) identifying which behaviours may indicate discomfort caused by the device, and 2) identifying potential design flaws in the devices that may suggest specific implications for design and help establish requirements.

### **5.5.1 Behavioural parameters to observe and use to understand biotelemetry impacts on cats**

Grooming is a composite behaviour which includes licking, scratching, biting or chewing the body's fur (Stanton et al. 2015). Its duration may vary a lot among different bouts (e.g. it can last the time of a tongue stroke or various minutes of constant licking), and it can be interrupted and resumed various seconds after the suspension. It is also a complex behaviour performed by cats for various reasons that range from cleaning purposes to stress release (van den Bos 1998). These aspects generated three problems in the measurement of grooming bouts. Firstly, scratching, that is one of the other behaviours we investigated, is both a sub-behaviour of grooming and a base behaviour in the cat ethogram (Stanton et al. 2015). Since any scratch was counted as an independent category of behaviour, grooming duration had to be calculated net from the scratching time, which complicated the recording of this behaviour. Secondly, although defining a grooming bout in detail (specifying the duration of pauses and defining when a bout starts and ends) allows for a precise post-recording measurement, in order to classify it, the observer had to make various arbitrary choices based on previous experience (e.g. deciding how many seconds define a pause). This added a degree of subjectivity to the quantification. The third problem is that the variability of grooming in terms of duration, composition (how many strokes, how many pauses, etc.), and purposes (cleaning, stress release, etc.) makes difficult to recognise a particular stimulus (e.g. the presence of the device) as the trigger of this behaviour. All these aspects

make grooming a difficult behaviour to measure reliably. Indeed, the statistical analysis of grooming supports its elimination as a possible indicator of discomfort to be used in the evaluative study of the cat-centred prototype (study 2), as it showed that both its frequency and duration did not significantly change between conditions. However, single strokes of licking in the neck and throat region emerged as signs of active interaction with the device and, especially in cats C1, C6, C7 and C10, they were performed in a way that implies directionality towards the devices. C7 was a typical example, where various tongue strokes performed alternatively on both sides of the neck with both PawTrax and Tractive were deemed to be part of an active interaction with the wearable. Thus, licking - defined as single or few tongue strokes directed at the site of attachment of the device - was extrapolated from the grooming behaviour and added to the active interaction category; it was then used for measuring the wearer's experience with the prototype.

Concerning the scratching behaviour, the statistical analysis also did not support its use as an indicator. However, the analysis of aggregated patterns of this behaviour strongly suggests a device-induced effect in those cats who incremented the scratching while wearing the devices. Indeed, in various occasions cats scratched the site of the device attachment insistently or repeatedly, suggesting that the reaction was consequential to the presence of the wearable. In particular, the outcomes suggest two possible interpretations. The first is that the device somehow generates a stimulus that needs to be relieved, as suggested by repeated scratching on both sides of the neck while wearing the PawTrax, whose mirroring collar eyelets bulge from the surface of the case (see Figure 5.1), touching the wearer's skin and possibly pressing on or itching the skin, thus provoking the scratching on both sides of the neck. The second is that, even if the urge to scratch is not caused by the device, the uniformly elongated shape of the PawTrax, along with its wide collar, prevents the wearer's claws from reaching the skin under its surface to relieve the itch, thus resulting in repeated attempts during which the cats kept scratching the device (either case or collar) rather than the skin underneath it. In other words, the insistent scratching observed may signal either a continuous stimulus generated by the device (where there is a protrusion on the inner surface in contact with the skin) or an impossibility to relieve an otherwise generated stimulus (when the cat scratches the device rather than the dermis). These considerations illustrate how scratching might actually be an indicator of discomfort, even though the statistical analysis did not give significant results, and how a careful ethological observation and analysis, comprising both quantitative and qualitative elements, is needed to understand the experience of animal wearers.

With regards to head and body shaking, from the results of the statistical analysis, the null hypothesis that the shaking average response is the same with and without devices has a low probability to be observed (i.e. of 3.8%, being the  $p$ -value = 0.038;  $p < 0.05$ ). This means that the increment in occurrences counted during the device conditions is *probably* not due to chance, but may depend on the presence of the device, which supports our conclusion

about the possibility that this behaviour indicates a device-induced effect. Although shaking is a relatively short event, repeated or consecutive occurrences, along with forceful shakings able to unbalance the cat's posture or movement, were noted as relevant patterns that could be a further sign of device-induced effects. However, these attributions to the shaking behaviour did not give rise to an insight about which particular device feature could have provoked an increment of the behaviour, although they strengthen the hypothesis that shaking could be an indicator of general impact and discomfort. Hence, shaking seems to be important as an indicator of device impact that could be used to assess a general stimulation (probably to the head) in the evaluation of successive designs. Thus, in testing the prototype, either the presence or absence of shaking was used to indicate an uncomfortable device.

The composite category of active interaction turned out to be especially valuable regardless of the number of times it was observed in each cat. The fact that a cat physically interacted with the device (with forepaws, tongue or teeth) provides strong indication that the device has an influence on the participant's behaviour. However, not all the cats had an active interaction with the tag and, for those who had, the intensity of the interaction varied in amplitude. This means that active interaction cannot be the only way to assess an impact on the wearer, since some individuals reacted less overtly (i.e. with an increase of head shaking or scratching rather than cuffing or biting the device). Hence, while an active interaction alone might be able to both indicate an impact and show what device feature may generate such impact, other parameters (e.g. head/body shaking) might be useful or needed as indicators of impact in participants who show less overt reactions to the presence of the tag. In other words, if an individual does not actively interact with a device it does not mean that he/she does not experience discomfort. Hence, it is important to have a way to assess a WX in such a case.

### **5.5.2 Design limitations that help establish wearability requirements**

The findings that show active interaction episodes point to the position and protrusion of the case as two design weaknesses in the Tractive device. From the observations, the bulky Tractive case obstructed, and even impeded, smooth movements of the neck when cats licked their throats. In some cases, this led to more conspicuous reactions against the Tractive, such as rearing on hind legs and cuffing or biting the device. Such active interaction occurrences appear to be related to the significant protrusion of the case and to the fact that the device was under the chin. On the other hand, no occurrences of cuffing and biting were observed with PawTrax, which has a slimmer case. Head rolling seemed also linked to the possibility that the bulkiness of the Tractive case might have been visually perceived. Our observations suggest that cats might see the case attached to their throats, direct their glance and focus their attention on it, then follow the case, which would move with the rotation of their heads.

Through the analysis of the cuffing or biting of the case, and rolling of the head, two requirements that are important when designing cat wearables were established: the first one is that protrusion should be kept to a minimum (e.g. by distributing rather than piling the electronics and battery components together); the second one is that the case should be positioned in an area of the neck not reachable by the cat's tongue (e.g. the nape).

Salient incidents such as insistent scratching suggests some design limitations of the PawTrax. If the elongated shape of the case and the collar width prevents the wearer's claws from reaching the skin, the area occupied by the device components must be an important design consideration. In this case, the Tractive *collar* is substantially narrower (9.4 mm) than the PawTrax collar (13.5 mm), and indeed double or multi scratching occurred less frequently with Tractive than it did with PawTrax, suggesting that the narrower collar allowed the claws to reach the irritated spot. Furthermore, the bulkier but more compact Tractive case was observed sliding around the wearer's neck thus exposing different areas of the skin and allowing the wearers to relieve themselves, while the more uniform PawTrax case did not slide around the wearer's neck thus preventing them from reaching the skin underneath. This suggests that the area (extension) of both collar and case should be kept at a minimum but in trade-off with the protrusion. It also suggests that the case should not cover the whole perimeter of the collar and that the collar should be able to easily slide around the neck to free sections of it (presumably, a sliding case may allow any part of the neck to be scratched). However, this feature would require careful consideration. Firstly, a movable case could constitute a safety hazard where mobility is associated with a loose collar, as this could get stuck more easily, for example, on vegetation. Secondly, observations of licking behaviour suggest that the best position for the case would be on the nape, so cats can freely lick their throat, which could not be maintained if the case could freely slide around the neck. A solution to address both issues might be a mechanism that allows the case to slightly slide on the collar in a restricted area of the nape, to free it when scratched, but that never allows the case to slide down as far as the throat or either side of the neck. Another solution might be to customise the size of the electronics so that they can be embedded inside the neckband, and to spread them along the collar, keeping the overall device as narrow as possible and very much like a simple collar such as those used for identification badges.

Another flaw suggested by the findings related to scratching behaviour is that any inner protrusion (i.e. in contact with the body) might generate a stimulus or exert pressure that might be difficult to alleviate. As a counter point, the clip that attaches the Tractive case to the collar has a smooth surface and, indeed, the cats did not scratch the neck in an alternate fashion, as they did with the PawTrax (which has inner eyelets). This supports the hypothesis that the eyelets of the PawTrax might be involved in the scratching impulse. Thus, discontinuities in the inner surface of the device in contact with the animal's skin should be avoided (e.g. eyelets, sewing points, etc.).

A further design flaw appears to exist where parts of a device catch the wearer's hair, as with the buckle of the Tractive collar. Especially, cats such as C4, C6, and C9 who have medium-long hair (see Table 5.1) scratched the nape where the buckle was located, suggesting that long fur gets trapped into the buckle mechanism thus pricking the hair follicles. This points to the requirement that collar fastening methods which catch tufts of fur (e.g. buckles or Velcro) should be avoided. Moreover, although for all cats the collars were fastened according to the manufacturer's guidelines, medium-long-hair cats were more difficult to fit properly. In particular, when the collar was put in place, it was positioned on top of the coat. As the wearer moved, their hair slipped above the collar thus freeing space and making the collar looser. This limitation in the study procedure indicates that the fur length plays a role in the sliding as well as the effective fastening of the device. Thus, another requirement suggested by the findings is that any fastening method should have the ability to adapt to the varying measurements of the wearer in order to maintain a constant hold. For example, the use of low-tension elasticated materials which provide low friction with the fur may allow the device to remain well fastened while moving around the neck when pushed during scratching.

A number of sequences show unambiguous reactions against the device, as a result of the physical interaction between the wearer and their environment, pointing to the importance of choosing the right material for the encasing. When C10 and C7 rolled their bodies on hard surfaces, their active reaction was likely triggered by the noise produced by the plastic case hitting the ground, as the cat reacted as soon as the device touched the floor. This suggests that the material used for the casing should be carefully considered to avoid it interfering with habitual behaviours such as rubbing against objects, surfaces and other individuals. In particular, routine rubbing to leave one's odour on another cat or on other surfaces in the environment is key in maintaining tight bonds within social groups and marking one's territory (Rochlitz 2005); however, the use of hard materials such as plastics could disrupt this important practice, either producing an auditive stimulus such a knock that irritates the wearer, or rendering the rubbing uncomfortable if the case exerts a pressure on the body when rubbed, or disrupting the behaviour if the case prevents the neck glands from spreading the wearer cat's scent on the rubbed cat or surface. On the other hand, softer materials, such as rubber, could emanate odours that interfere with cats' highly sensitive olfaction (Rochlitz 2005). The choice of materials for the device should take these issues into account. Thus, two requirements related to the material were extrapolated from this analysis: that it should not be hard and that it should be odourless.

### **5.5.3 Summary of results and discussion**

The aims of this study were to investigate a cat's experience in wearing off-the-shelf devices (in terms of discomfort) and to identify wearability flaws from which to establish design requirements. By adopting an ethological approach, we interpreted the behaviours of cats in order to identify indicators of discomfort that were used to evaluate the experience of



wearing a prototype derived from the application of the WCF (chapter 7), and to find limitations in the devices' design that elicited a cat-specific requirement analysis with which we established device requirements for wearability, which were then compared with those established by means of the WCF (chapter 6).

With respect to these two objectives, we identified the following indicators and requirements:

1) Indicators relevant to the evaluation of devices fastened to the neck:

- licking of collar zone - by means of a qualitative analysis that accounts for the way in which the behaviour was performed;
- scratching - by means of a qualitative analysis for individuals who showed an important increment of the behaviour with respect to a control situation;
- head/body shaking – by measuring how many times the behaviour was performed with respect to the control.

2) Design features relevant to the cats' reactions and requirements (Table 5.12):

Design feature	Cat's reaction	Empirical requirements
Exterior protrusion	Extrapolated from the observed direct contact between the tongue and the case, grasping and biting of the case, and instances of the device hitting the floor	1) Protrusion should be kept at a minimum (e.g. by not piling the electronics together but distributing them along the available perimeter and over the available surface, albeit in trade-off with 3) covered area)
Position of the case	Extrapolated from observed licking and scratching behaviour	2) The case should be positioned on an area of the neck not reachable by the cat's tongue (e.g. the nape)
Area covered by collar and case	Extrapolated from observed scratching behaviour	3) The area of both collar and case should be kept at a minimum, identifying an appropriate trade-off between covered area and protrusion
Protrusion of the device inner surface in contact with the animal's skin	Extrapolated from observed licking and scratching behaviour	4) Eyelets and similar inner protrusions should be avoided
Collar fastening method (e.g. buckle, Velcro straps, etc.)	Extrapolated from observed scratching behaviour	5) Buckles and other fastening methods that may catch tufts of fur should be avoided, especially for medium and long-hair cats
Case material	Extrapolated from observed rubbing and body-rolling behaviour	6) Hard materials that might disrupt rubbing should be avoided 7) Ensuring that any soft materials used are odourless
Collar material	Extrapolated from the difficulty of fitting the collars	8) Low-tension elasticated and frictionless material that fits the neck

	to cats with different hair lengths	and avoid the collar to get loose should be preferred
Movement of the collar around the neck	Extrapolated from observed scratching behaviour	9) Fastening mechanisms should allow the case to slide along the collar within a restricted range of the nape

*Table 5.12:* Design features that, based on the participants' reactions, could be redesigned to meet wearability requirements expressed by the participants' behaviour.

While these results served the evaluative phase of this research, the ethological approach adopted enabled us to assess a cat's experience in a relatively objective way. We recognised that a major risk of investigating an animal experience is to anthropomorphise the interpretation of behaviours with human emotions and intentions (Martin and Bateson 1993, p. 18). As a way to mitigate the risk of human interpretational bias while maintaining a strong focus on the experience for wearers, we employed an observational protocol that allowed for the collection of data that could be analysed both quantitatively and qualitatively. A quantitative assessment enabled us to measure and interpret responses whose meaning was potentially ambiguous. More specifically, it helped us discriminate whether usual behaviours such as grooming, scratching and head/body shaking, that are part of the cats' normal repertoire, increased in response to the presence of the device the cats wore (e.g. because tags irritated them) or to other environmental stimuli. On the other hand, a qualitative assessment helped examining singular behaviours directed to the device itself (e.g. grasping or chewing the device), which more explicitly derived from the presence of the device (in that they could not occur if the device was not there).

Quantitative and qualitative data were triangulated to yield complementary findings that could be used to better understand the experience of wearing a device. Overall, eleven cats over thirteen (only C2 and C5 excepted) either increased their licking, scratching, or head/body shaking behaviours, or showed explicit reactions addressed at the devices, or both. The fact that cats had an individual and diversified response showed a need for analysing behaviours both quantitatively and qualitatively in order to truly understand their experience. For example, the quantitative findings show that there is not a statistically significant difference in the scratching behaviour of the cats between the control and the two devices conditions. Statistically, this would suggest that cats scratch their neck and throat when they wear a device just as they normally do when they do not wear it; it could be either concluded that scratching does not indicate discomfort or that the device does not produce such a discomfort to trigger a scratching response. However, looking at the data from each cat, eight of them (i.e. C3, C4, C6, C7, C8, C9, C10, and C12 – Table 5.7), scratched in a way that is qualitatively meaningful. For example, several instances of scratching the same spot on the neck concentrated in a same brief sequence. Such instances cannot be discounted as irrelevant since they leave little doubt about the wearer's discomfort. Thus, the overall data for scratching suggest that the presence of the device produces an impact on the wearer, in spite of the absence of statistical significance. Hence, when evaluating the

wearability of a device (with cats), scratching could still be used as an indicator of a negative impact (given that scratching in cats is a behaviour whose function is to relieve irritation or eliminate detrimental external agents, such as parasites). On the other hand, statistical analysis attributed a significant difference to head and body shaking between experimental conditions. For this category of behaviour this is a standalone result. In fact, head/body shaking is a fast and automatic reaction that does not lend itself to qualitative descriptions that provide additional information about discomfort beyond the mere quantification of the behaviour (in other words, although we accounted for four shaking patterns in Table 5.9, we did not use such information when we established the requirements, regarding shaking as valid for measuring the extent of an uncomfortable experience but not for qualifying it). Thus, behaviour quantification seems to be better for treating shaking as a potential indicator, since in this case a statistical analysis provided a more compelling case for the meaning of shaking as an indicator of discomfort.

These findings illustrate the complementary role that the quantitative and qualitative treatment of the experimental data played in the study. On the one hand, the quantitative analysis from all the cats helped us identify behaviours that may indicate (or not) a reaction associated to the presence of the device. On the other hand, the qualitative analysis of particular incidents of active interaction with the device helped us assess a degree of discomfort when it was not detectable through the indicators.

To the best of our knowledge, no biotelemetry evaluations are reported in the literature that adapt a method used to conduct systematic ethological observations for use as a tool to assess the impacts produced by biotelemetry devices and conduct a requirements analysis. Beyond this research, though, the application of the ethological observation method in ACI research could serve both as requirements analysis tool and, more broadly, as a way of reducing researchers' interpretational bias and thus improve the objectivity of their observations, while allowing them to account for singularities that may be highly significant when designing animal-centred technology.

## **5.6 Chapter summary**

This chapter reported a pivotal empirical study aiming at understanding cat's experience of wearing devices in order to obtain essential information to be used for investigating wearability from an animal wearer's perspective. The cats' behaviours towards off-the-shelf tags identified by means of an ethological analysis were employed to individuate signs of discomforts and flaws in biotelemetry physical design, from which wearability requirements were empirically established. The indicators of discomfort will serve for measuring wearability improvements of a prototype built using the WCF as a tool facilitating a 'heuristic' requirement elicitation (chapter 7). At the same time, the empirical requirements will be compared with those established by means of the WCF, to evaluate whether the framework was useful to designers when conducting a requirement analysis (chapter 6).

## **6. APPLYING THE FRAMEWORK: Establishing requirements through the WCF**

Chapter 4 presented a first version of the Wearer-Centred Framework (WCF) as a multi-species tool potentially capable of helping designers to achieve the overall goal of wearability in animal-borne devices. After the WCF was developed, the research objective became that of attesting whether the WCF is a useful instrument for inspiring and scoping the design towards wearability. To achieve this evaluation, the WCF was administered to three teams of designers, who collaboratively used it to perform a requirements activity specific for domestic cats (chosen as a model species) (**Question 2** - *How could the framework be applied during the design process*). This chapter describes the rationale, method, and outcomes of the collaborative workshops, analysing designers' activities and dialogues with the aim of identifying wearability requirements heuristically. Then, the chapter maps the requirements obtained during the workshops with the ones empirically established in study 1 and previously reported in chapter 5, providing a first validation of the WCF's usefulness.

### **6.1 Identifying requirements and developing alternative designs**

#### **6.1.1 Rationale**

An interaction design project that aims at improving an existing technology would start from acquiring a better understanding of the (user) interactors' requirements to determine what needs to be changed (Preece et al. 2015, p. 350). This is typically done by means of requirements activities. Requirements activities can be either exploratory or more focused exercises on particular aspects, carried out at the beginning of each iterative cycle in the design process with the aim of establishing a set of requirements that serves as a basis to start designing (Preece et al. 2015, p. 351). Commonly in User-Centred Design (UCD), information that is used for carrying out a requirements analysis (e.g. tasks performed by users, type of context of use, etc.) is collected directly from the interactors, for example by means of usability tests. Common data-collection methods for requirements elicitation are questionnaires, interviews (focus groups included), and observations with user participants when, for example, they are asked to engage with an artefact, or discuss a concept (Preece et al. 2015, p. 361). However, in this research, the interactors of interest are animals and, clearly, neither questionnaires or interviews can be adopted for exploring requirements with them (if not through their guardians' or animal experts' opinions (Lawson et al. 2016)). On the other hand, observations of animals engaging with a wearable device require the participants to be fitted with a tag in order to explore how they react. Although this is a viable approach (as we demonstrated with the off-the-shelf wearability study described in chapter 5), avoiding to physically involve animals, at least at the early stages of the design process, is advisable due to the potential disturbance generated by tags.

Especially (but not only) for free-roaming individuals, establishing requirements through wearability tests - in which animals' interactions with a wearable are observed - poses

ethical and practical problems. From an ethical point of view, the main problem arises from the fact that animals cannot provide informed consent to procedures that are likely to affect them. Their involvement is based on the assumption that they might tolerate or get accustomed to a tag, that their guardians consent on their behalf for the animals' benefit, and that such benefit outweighs the impact of being fitted and carrying a device. However, because the device can still be a source of distress, animals' direct involvement should be reduced as much as possible. From a practical point of view, following free-ranging animals to observe how they respond to a wearable is not always feasible. For example, they might move to locations that are inaccessible to the observer or the camera eye. Working with captive, sheltered, or housed animals might enable the observer to have individuals constantly in view. However, confined environments poorly represent the complexity of wild contexts, therefore this procedure is not always suitable.

Notwithstanding these issues, in order to truly understand wearers and design wearables that afford them good wearability, designers still need to elicit requirements that derive from the wearers' needs, characteristics, activities, and environments. Here the hypothesis is that, by helping designers to reflect on the wearability aspects of a device at an early stage, the WCF could, at the same time, help designers to identify an initial set of requirements with which to start designing, and make it possible to postpone the direct involvement of animal participants until later on in the design process, when prototypes are likely to already fulfil a significant number of wearer needs. In other words, this research argues that detecting early requirements heuristically before animals are fitted with a wearable is better than observing their responses to prototypes in order to establish early requirements. We argue that the use of the WCF could reduce the need to physically involve animals in repetitive obtrusive wearability tests, while maintaining the focus on animal wearers as stakeholders. This is especially important in the case of wildlife, which may be particularly affected by the iterative nature of a design process when it means re-testing the wearability of a product at each design cycle (for example, is it ethical to capture, release and re-capture animals for testing iterative versions of a prototype?). From a more practical perspective, the use of a wearer-centred framework might also facilitate the application of UCD values to the design of products whose wearability would be difficult to test when animals have free-roaming lifestyles and elusive habits.

Thus, our WCF was conceived as an instrument to support designers with:

- understanding how an animal wearable should be constructed and attached to acquire and provide data without interfering with the wearer's behaviour and activities, taking into account animals' needs, perception, activities and environments (heuristic approach);

- carrying out an initial requirements analysis when designers do not have access to animals, or when it is not ethical to involve them, or when they desire to reduce the direct involvement of animals while still accounting for their perspective.

### 6.1.2 Approach

In order to explore if the WCF was able to inform and, at the same time, systematically guide designers to complete an initial requirements analysis in relation to wearability, we conducted a series of collaborative requirements identification workshops ((Gottesdiener 2003), see section 3.2.2) in which we invited human participants to ‘become’ designers and use the WCF for establishing wearability requirements and proposing alternative designs for an electronic cat tracker. As described in section 3.2.2, such a heuristic requirements activity was conducted by means of a workshop method slightly modified with respect to what was proposed by Gottesdiener. In particular, while for Gottesdiener it was important to involve at least one representative for all the stakeholders of a product, we grouped our participants in homogeneous teams as we were interested in assessing how different stakeholders value a conceptual tool, rather than developing a product that could correspond to the expectations of all stakeholders. In other words, understanding whether the WCF is able to guide different categories of stakeholders (see section 3.2.2 for more detail). By ‘heuristic approach’ we mean an inspection method that does not involve [users] and whereby *“the researcher has to imagine or model how an interface is likely to be used [worn in this research]”* (Preece et al. 2015, p. 460)

### 6.1.3 Process

#### *Participants*

We identified three categories of stakeholders with which to test the WCF. They were computer scientists, biologists, and cat carers. We carried out a collaborative requirements workshop for each team, for a total of three workshops. Each workshop team was composed of four members, with an overall number of twelve human participants.

For Gottesdiener (2003), developers and engineers are part of the stakeholder category of ‘suppliers’ and therefore they should be involved during the design process of a product. Hence, we initially organised a workshop with four computer engineers and designers working in the School of Computing and Communications at The Open University (OU). We chose a particular group of colleagues who attended a course on prototyping provided by the +ACUMEN-IDEO organisation<sup>34</sup> several months before our study. During the course, they gained knowledge about UCD concepts, became acquainted with the method of collaborative workshops, and learnt to collaborate to develop prototypes. Except for one of the participants, who was a dog carer, the others did not have any experience with animals; and none of the four participants has ever had a cat. We deemed this group ideal for testing

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<sup>34</sup> Human-Centered Design 201: Prototyping - <https://www.plusacumen.org/courses/prototyping>.

our WCF, because they were a target stakeholder group and because they were familiar both with the method and with each other. Our objective was to see how people who are already acquainted with typical design tools and techniques were using the WCF.

After this first workshop, we recruited co-workers in another two units of The Open University. One team was composed by three biologists that work with laboratory animals such as rodents. The biologists did not have any experience with interaction design techniques and concepts. Two of them had had pets as children but not any longer; one was a dog and cat guardian at present. The team was completed by an interaction designer with no knowledge about animals since we needed a balancing member that could help detect unfeasible solutions and help biologists to focus on design aspects about which they knew little. With this team the aim was to explore how people that handle animals for their work could use the WCF. We deemed this team's perspective to be important as they have experience of animals but not (necessarily) within affective relations level.

The third team was composed of four members of an OU club specialising in prototyping, crafting, and modifying technological gadgets, three of whom were cat carers. Our aim was to see how the WCF was used by people who have an affective relationship with animals and who are also interested in technological gadgets as users. The fourth team member was not caring for any pet; *their* participation was included to align the number and skills of participants of this workshop with the other two.

Each team was as much as possible organised to include people with a similar background, and familiar with each other. One reason for this was to differentiate the composition across teams and thus explore whether the background of participants would have influenced the application of the WCF. The second reason was to facilitate the tight schedule of a four-hour workshop since we deemed that people who knew each other would feel more at ease than they would with non-acquaintances and would be likely to get to work more efficiently by having a more open discussion and participating more proactively (Chick 2017). Four hours was the maximum time available that participants agreed to give us. Participants (subsequently collectively referred to as 'designers' regardless of whether they were computer scientists, biologists or cat carers) took part in the workshops on a voluntary basis and consented in writing to the use of the data acquired through the workshops for reports and publications. Their participation was approved by the Human Research Ethics Committee of The Open University (Ref. N. HREC/2016/2202/Paci/1, see Appendix 1) and incentivised with a small amount retail voucher.

Ultimately, our objective was to understand how different categories of stakeholders used the WCF as a guiding and inspiring tool for designing a new concept (i.e. wearability *in animals*) to which they were not familiar with.

### *Workshop schedule and activities*

The three workshops were scheduled following a template derived from the +ACUMEN-IDEO.org course for roughly prototyping a physical artefact. The use of this kind of workshop was a way of facilitating a collaborative design process and allowed us to perform a ‘quick and dirty’ requirements analysis and prototyping activity in a relatively short time.

The facilitator briefed each team about the aims of the workshop, presented the problem of impacts on animal wearers, presented the WCF and explained its components in detail, and guided each team through the sequential steps of the workshop, employing different techniques to facilitate the participants to apply the WCF. The workshops consisted of four parts: an introduction phase, in which the aim was to expose the problem of impacts in biotelemetry and explain the WCF role in the design process; an instruction phase, in which the WCF components were illustrated; an exploration phase, in which designers were asked to apply the WCF to a case study for establishing wearability requirements; and a crafting phase, in which each team was asked to make a low-tech mock-up based on the requirements discussed during the exploration phase. Each workshop comprised the following designing techniques and tools:

- For the introduction and instruction phases: a short personal questionnaire helping participants to think about one’s own ‘inner craftiness’ and share it with the others; and a warm-up exercise to move the designers’ mind from ideas to making actual things (Appendix 3).
- For the exploration phase: a ‘cat persona’ giving designers a concrete case with which to work; charts listing many variables relating to animals’ biology to help designers think about what was important for the cat persona; a brainstorm activity helping designers to propose ideas that might address an impact; a selection activity helping them to collaboratively choose the features of a device to be designed that would provide good wearability for the cat persona.
- For the crafting phase: a ‘make it’ activity helping designers to collaboratively shape a low-tech mock-up; designers had at their disposal a variety of crafting materials (e.g. cardboard, paper, textiles of various textures and elasticity, bandages, rubber bands, strings, laces, straws, Velcro, paper clips, normal and duct tape, etc.) that they could use to build their device idea as well as a dummy cat that functioned as a physical representation of the cat persona and that could be used to try on prototype ideas; additionally, since this was a simulative exercise, designers could also imagine having in their hands any kind of material they wished.

Figure 6.1 depicts one of the teams during one of the discussions and the results of the brainstorm and crafting activities. The slides used to propose all the activities reported above and the list of materials used during the workshops can be found in Appendix 3. This



particular team imagined a soft furry collar of the same colour of the stuffed cat toy used as a dummy with the internal electronics evenly distributed along the length of the collar.

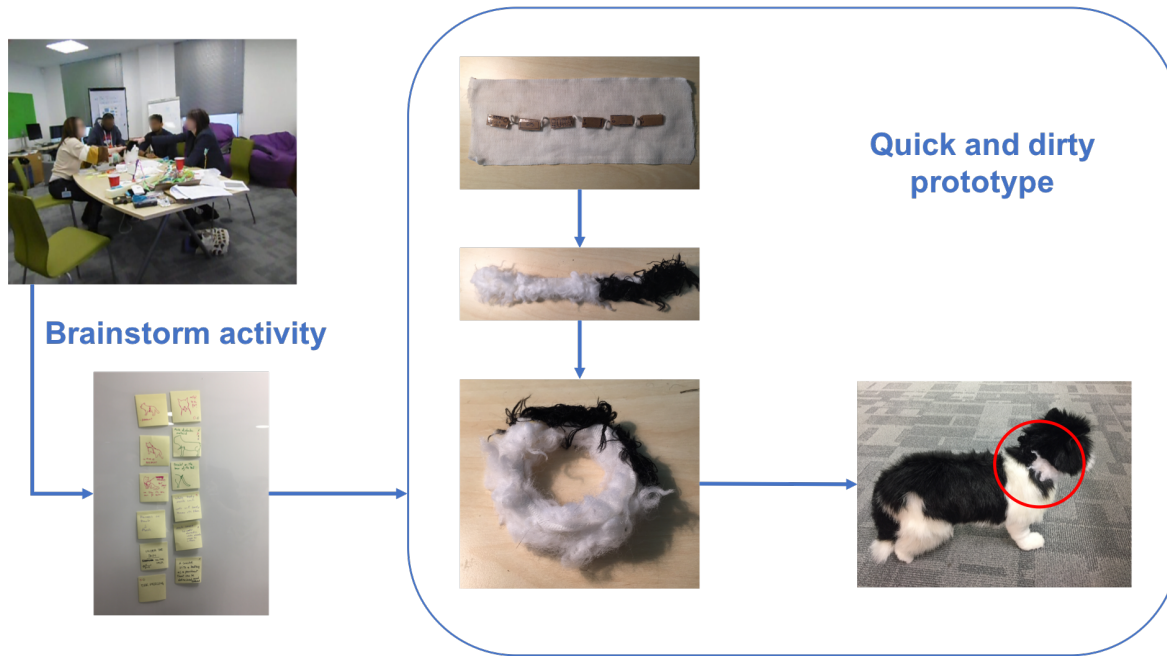


Figure 6.1: Example of workshop activities. The members of the team sketched their ideas on post-its during a brainstorm activity. Then, they chose among the ideas those to be designed during a 'make it' activity.

All the workshops were administered in the same order and included the same 'facilitating' techniques and crafting material.

#### *Data collection and analysis*

During the workshops, designers were invited to confer with each other and share their thoughts, ideas, and design propositions. They were also asked to describe the low-tech mock-ups crafted during the 'make it' activity and to explain their design details. Designer's conversations and activities were video-recorded to facilitate a post-study data process, which consisted of transcribing the participants' dialogues and linking their words to the crafting actions they performed during the crafting activity. From the transcripts, quotes were extrapolated and analysed for two purposes:

- 1) to understand whether the WCF was useful to designers to conduct a requirements analysis (this will be detailed in chapter 8), and
  - 2) to gather requirements that had the potential of contributing to designing for wearability.
- A requirement is defined by Preece and colleagues as a clear, unambiguous, and specific statement that can have various levels of abstraction (Preece et al. 2015, p. 353). To formulate them, we firstly extrapolated all the designers' statements that referred to the features of their mock-ups at any level of abstraction, and successively we categorised the statements as general high-level requirements (HLRs) or specific descriptions of how to

accomplish the HLRs. In this way, we identified three sets of wearability requirements<sup>35</sup> (HLRs and related specifications), one set for each designer team. These requirements are reported in the next section.

#### 6.1.4 Workshop Requirements

The three sets of HLRs and related specifications are reported in Table 6.1. Some requirements were the same or analogous across the three teams; others were unique to only one team.

FEATURE / QUALITY	COMPUTER SCIENTISTS		BIOLOGISTS		CAT CARERS	
	HLRs	SPECIFICS	HLRs	SPECIFICS	HLRs	SPECIFICS
Kind of attachment 1	Least obtrusive and not reachable by self-grooming	Keep the components near the shoulder blades/base of the neck; built-in collar	Least obtrusive for when the cat rub and groom	Keep the components near the shoulder blades/base of the neck; built-in collar	The place that seems to bother the cat the least	Not further specifics given; built-in collar
Kind of attachment 2	Least obtrusive and not reachable by self-grooming	Mesh on shoulder blades	Least obtrusive for when the cat rub and groom	Clip the components to the shoulder blade fur	Not mentioned	Not mentioned
Weight of device	Super-light	Low profile, light materials	As light as possible, but depending on usage and therefore on battery capacity	Light materials	Reduce the weight as much as possible, avoid a weight hanging under the cat's neck	Not mentioned the kind of way to keep it light, built-in collar avoids hanging weights
Colour of whole device	Blending natural fur	Same colour of the cat (black and white)	Same colour of the fur	Same colour of the cat (black and white)	Something that does not attract other animals	Same colour of the cat (black and white)
Material of collar	Softy, stretchy & no scratchy/chafing	Soft fabric/textile	Soft, smooth, plain, light, thin, sophisticated, flexible	Either soft fabric or leather-kind (as normal collars in the market)	Soft and flexible	Silicone wrap/band
Width of collar	Narrow width	According to how the electronics can be designed narrowing	Thin but not threadlike (otherwise it cuts the skin)	Collar width like standard cat collars	Same width of components (see shape of components)	According to how the electronics can be designed narrowing
Detachability of collar	Intended as a safety measure (see safety)	Intended as a safety measure (see safety)	Keep the collar attached all the time for habituation	Detachable by owner when necessary	To reduce intrusiveness of the collar	Keep the collar attached and recharge /download wirelessly
Texture of collar	Soft and furred that do not disrupt grooming	Fur-like material all around the collar	Soft if fabric, edges not sharp as typical leather belts	Edges rounded and smooth if material is leathery	Soft and rubbery	Silicone material
Fasten method	No scratchy/chafing	Unique piece of elasticated collar (without buckle, seams or Velcro strips)	Easy to attach	Through buckle	To make the collar adjustable	Through Velcro dots or any kind of clasp

FEATURE / QUALITY	COMPUTER SCIENTISTS		BIOLOGISTS		CAT CARERS	
	HLRs	SPECIFICS	HLRs	SPECIFICS	HLRs	SPECIFICS
Size and distribution of components (batteries, tracking and charging units, wires)	Small and thin but more pieces	Distributed at equal intervals around the collar to balance the weight	Longer than larger, one battery and one piece of electronics	Distributed along the collar but kept separated, with the electronics in nape position, to balance the weight	As small an area as possible, small and thin components but in more pieces, elongated if necessary, split the battery capacity in two cells, split the PCB in two sections, one GSM unit, one GPS unit	Pile the electronics together (PCB+PCB, GSM+GPS), but not the two battery cells, distribute the components around the collar but keep them separated to maintain flexibility, it will be slightly unbalanced, but this is a trade-off
Shape of components	Thin, narrow	Width same area of the collar	Thin, elongated and possibly flexible	Adapt the shape of electronics to the shape of the collar, collar flexible enough to follow the curvature of the cat's neck	Thin and narrow, flexible electronics as much as possible, or if not possible, electronics put in a flexible way	Width same area of the collar, potentially electronics slightly wider, attached through wires or conductive ink
Protrusion of components	Protrusion kept at a minimum with very thin components, no bumps internally (inward)	Components not piled, distributed around the collar	Two very thin bumps	Components not piled, distributed around the collar	Avoid a device hanging under the cat's neck, no bumps internally (inward)	Batteries distributed, thin electronics piled, keep the back of the collar flat (i.e. inward surface)
Orientation of components	Possibly, not to border outward the edges of the collar	along the collar, positioned end-to-end	Possibly, not to border outward the edges of the collar	along the collar, positioned end-to-end	not to border outward the edges of the collar, or potentially slightly	along the collar, positioned end-to-end
Case	Necessary for protecting the components (waterproof), lighter and flexible as possible	Wrapping the components in candy-coat/waterproof material	For extra protection of the electronics	Electronics embedded inside a thin silicon case, inside the collar	For both holding and protecting (waterproof/water resistant) the components	Components sealed into a silicone collar/cover

<sup>35</sup> Now on, the term 'requirement' is used to indicate both high-level and more specific requirements.

FEATURE / QUALITY	COMPUTER SCIENTISTS		BIOLOGISTS		CAT CARERS	
	HLRs	SPECIFICS	HLRs	SPECIFICS	HLRs	SPECIFICS
Attachment of components to the collar	Components embedded into the collar, no bumps internally and externally.	Components sandwiched inside two layers of the collar/wrapped inside the collar	Electronics embedded into the collar (one bump for the electronics), battery external to the collar	Electronics sandwiched inside two layers of fabric or leather, battery inserted into an external case	Components embedded into the collar, bumping externally (outward)	Components sandwiched inside a flat silicone collar back, sealed with another silicone layer in order to bump externally
Connection of components	Components connected through wires, maintain the elasticity of the elastic collar	Longer and slightly coiled wires (like telephone wires)	Components connected through conductive ink or tape that become a piece with the silicone case	Embedded in the silicone wrap/case	Components connected through wires, maintain the flexibility of the collar, potentially through conductive ink	not further specification given
Frequencies	Avoid any acoustic frequency	Electronics and batteries connected through wires and not wirelessly	Avoid any acoustic/ultrasound frequencies	Soundproof enclosure; no bells	Not mentioned	Not mentioned
Light spectra	Not mentioned	Not mentioned	Avoid any light	Do not put any LEDs	Not mentioned	Not mentioned
Odours	Not mentioned	Not mentioned	No odour materials	Not further specifics	Not mentioned	Not mentioned
Batteries	Recharging the batteries wirelessly	Rechargeable with wireless charging station distributed in the home	Easily removable, avoiding components overheating	Not embedded into the collar as the electronics, but on a small case where it can be inserted, set of two batteries	Recharging the battery wirelessly	Spreading the charging stations under the bed, bottom of food bowl, favourite spots
Retrievability of device	Signal for retrieving the collar if lost	Add-on to retrieve the device or through GPS	Signal for retrieving the collar if lost	Locating it through the GPS	Owners do not want to lose the device	Not further specification given
Safety of device	Avoid risk of strangulation and get caught, easy release of the cat if entangled	Stretchy textile that easily pull out from the neck and easily stretch adjusting to the neck (low tension)	Safe release mechanism if the cat gets entangled	Breakable clip like the lanyard one	Safe release mechanism if the cat gets entangled	Easy unclasp mechanism

FEATURE / QUALITY	COMPUTER SCIENTISTS		BIOLOGISTS		CAT CARERS	
	HLRs	SPECIFICS	HLRs	SPECIFICS	HLRs	SPECIFICS
Adjustability of the collar	Close fitting	Elasticated fabric that stretch to fit the neck	As standard collar guidelines	Through the buckle holes	Collar adjustable to fit different cat sizes	Row of Velcro dots or clasp
Visibility	Not mentioned	Not mentioned	Inconspicuous for other animals	Not further specification given	Inconspicuous for other animals	not use reflective material that attract other animals
Aerial	Not mentioned	Not mentioned	Not mentioned	Not mentioned	Built-in, part of the entire collar so that reception is not affected	Thread aerial antenna that goes all around the collar
Adds-on	Not intended	Not intended	Not intended	Not intended	To be more sellable and user personalised	Possibility of modular device to add additional sensors

Table 6.1: The three sets of HLRs and related specifications for each workshop team.

To appreciate the extent of similarity and difference across teams, we categorised them in three lists: requirements that were analogous or the same across the three teams (List A), requirements that differed across the three teams (List B), and requirements that were analogous or the same across only two teams (List C).

### Similar requirements considerations across the three teams (List A)

All the three teams established that the device must be positioned on the least intrusive and least reachable body location for the cat. This was specified to be near the shoulder blades or at the base of the neck by both computer scientists and biologists, since this is a spot that cannot be groomed, and is in fact where veterinarians apply spot-on antiparasitic solutions. Cat carers were not so specific; nevertheless, in accordance with the other two teams, they ended up crafting a collar, which would embed the electronic components and keep it exactly near the designated area. Both computer scientists and biologists also proposed a second kind of attachment; respectively a hair-catching mesh and a hair clip to be positioned on the cat's *shoulder blades* (i.e. position is consistent with the above). However, in the end, both teams chose a collared solution, due to the difficulty of pulling the hair through the mesh holes in one case, and to the potential unreliability of a clip's attachment to the fur in the other instance.

All three teams established that:

The *overall device* (i.e. electronic components and collar) should be as light as possible and blend in with the animal's fur colour to minimise its intrusiveness and visibility; it should be easily released in the case of wearers getting entangled and somehow easily retrievable if lost.

The *collar* itself should be made of flexible material and have a soft texture to provide comfortability, and its width should be narrow to minimise intrusiveness; it should wrap around a thin protecting case that contains the electronic components (i.e. batteries, tracking and charging unit, wires) so as to maintain comfortability qualities to the overall device.

The *electronic components* should be narrow and thin, and their outward protrusion should be minimal to minimise height and width of the overall device; hence, they should be oriented along the collar line and be distributed along the collar line. Also, they should have no inward protrusions so as not to poke the neck of the animal. The electronic units and batteries should be physically connected through some conductive material (wires, conductive ink or tape) that maintains the elasticity and flexibility of the device.

In terms of specifications derived from the more general HLRs, in some cases, they were the same among teams. For example, all designers agreed that the electronics had to be aligned end-to-end, and that the collar had to be black and white to accord with the fur of the dummy cat that was used to represent the cat persona during the workshops. In other instances, the specifications were different though obtained from the same HLRs. For example, a soft material was specified as synthetic fur textile by the computer scientists, fabric or leather by the biologists, and silicone by the cat carers.

#### *Different requirements considerations across the three teams (List B)*

Some requirements were accounted for differently across the three teams:

Although all the three teams established that the device should be easily released in case of wearers getting entangled, its detachability was a quality discussed differently across them. The computer scientists accounted for the importance of making the device detachable precisely for safety reasons; hence, their device was stretchy and easy to pull off the neck. The biologists thought that, for habituating the wearer to its presence, the device should be left in place as much as possible, but they also acknowledged the fact that cat guardians might need to easily detach and reattach the collar. For the cat carers too, keeping the collar attached all the time was a way of reducing its intrusiveness. Their assumption was that the collar would become part of the body and the animal would get used to it more easily than if it was periodically put on and taken off. However, the cat carers meant the device to never be detached, not even for charging purposes. At the same time, though, both biologists and

cat carers identified a safety requirement that would be met by a release mechanism that would open the collar and free the cat in case of entanglement.

With respect to the fastening method and adjustability of the collar, the computer scientists considered these in relation to the potential impact that the device might have by scratching or chafing the skin, or pull the cat's hair; hence, they avoided the use of Velcro strips or buckles and opted instead for a unique piece of close-fitting elasticated fabric that stretches to fit the neck. The biologists considered the need for the collar to be easy to attach, so they chose to use standard cat-collar buckles, while the cat carers prioritised the need for making the collar adjustable to the cat's neck size, thus opting for Velcro or clasps.

The cat carers addressed the problem of obtaining good aerial reception proposing to use a built-in thread antenna extended all around the collar. They also proposed to enhance the tracker with modular adds-on so that the collar could be personalised to (human) user functional requirements and thus make the device more sellable. They were the only team to think about these matters.

The biologists were the only team to establish that light spectra and osmic material should be avoided, on the grounds that the first aspect may negatively affect camouflage and the second one may irritate the sensitive cat's sense of smell.

#### *Similar requirements considerations across only two teams (List C)*

Distributing chargeable wireless stations around the cat's living spaces for charging batteries was considered a way to decrease the size and weight of the electronic components by both the computer scientists and the cat carers; in this scenario, power units would be recharged every time the animal rested near lead-up spots, thus reducing the possibility that the device would run out of energy and in turn enabling the use of smaller battery components. Instead, the biologists looked at the exchangeability of batteries and therefore at the need to easily remove them from the collar for charging purposes.

The need to avoid emissions in the form of sound frequencies was considered by both the computer scientists and the biologists. The biologists also included ultra and infrasound in their considerations.

Both the biologists and the cat carers established that a device should be inconspicuous for other animals interacting with the wearer, with the cat carers also specifying that for this reason reflective material should be avoided.

Table 6.2 summarises the wearability requirements belonging to each list.

List A – Similar requirements considerations across the three teams
<ul style="list-style-type: none"> <li>- Device positioned on the least intrusive/reachable body location</li> <li>- Device as light as possible</li> <li>- Device blend in with the animal's fur colour</li> <li>- Device easily released in case of entanglement</li> <li>- Device easily retrievable if lost</li> <li>- Collar made of flexible material and having soft texture</li> <li>- Collar width should be narrow</li> <li>- Collar should wrap around a thin protecting case</li> <li>- Electronics narrow and thin</li> <li>- Outward protrusion should be minimal</li> <li>- Electronics oriented / distributed along collar line</li> <li>- No inward protrusion</li> <li>- Electronics physically connected</li> </ul>
List B - Different requirements considerations across the three teams
<ul style="list-style-type: none"> <li>- Detachability <ul style="list-style-type: none"> <li>- Designers in computing: collar easily pull off if entangled</li> <li>- Biologists: easy to attach collar (for usability)</li> <li>- Cat carers: never detaching the collar</li> </ul> </li> <li>- Fastening method / adjustability <ul style="list-style-type: none"> <li>- Designers in computing: unique piece of elastic fabric</li> <li>- Biologists: buckle</li> <li>- Cat carers: adjustable Velcro or clasp</li> </ul> </li> <li>- Aerial: threadlike (from cat carers)</li> <li>- Light / odour features: to be avoided (from biologists)</li> </ul>

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List C - Similar requirements considerations across only two teams

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- Charging method
    - Designers in computing + cat carers: wirelessly
    - Biologists: batteries exchangeable
  - Sound frequencies
    - Designers in computing + biologists: to be avoided
    - Cat carers: not mentioned
- 

*Table 6.2: Wearability requirements established by the three teams of designers divided into lists.*

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## 6.2 Evaluating the workshop requirements

As discussed in section 6.1.1, one advantage of establishing requirements heuristically by means of the WCF is to avoid the over-involvement of animals in wearability tests. However, as a heuristic approach, applying our framework might not necessarily prevent designers from identifying requirements that do not accurately reflect animal wearability concerns (Preece et al. 2015, p. 460). In order to evaluate whether the WCF actually informed designers' thinking about animal wearability, we compared the workshop requirements in Lists A, B, and C above with the requirements identified during empirical study-1 (chapter 5). Table 6.3 shows the requirements respectively derived from study 1 and from the workshops, placed side by side against a device feature or quality. The objective of this comparative analysis was to appreciate the extent to which the requirements corresponded. We investigated such correspondence by discussing whether the empirical study requirements and the workshop study requirements showed any equivalence in addressing an aspect of a cat tracker's physical design; that is, whether the respective findings from these studies suggested equivalent requirements to address wearability issues. The aim of the comparison was also to see whether the empirical study identified requirements that the use of the framework did not identify, or vice versa.

Feature / quality	Empirical requirements	Heuristic requirements
a) Exterior protrusion	Protrusion should be kept at a minimum (e.g. by not piling the electronics together but distributing them along the available perimeter and over the available surface, albeit in trade-off with covered area)	Components should be narrow, thin, and distributed along the collar to avoid protrusion  Case should protrude minimally outward the edges of the collar
b) Position of the case	The case should be positioned on an area of the neck not reachable by the cat's tongue (e.g. the nape)	The case should be positioned on the least intrusive and least reachable place on the cat's body (i.e. near the shoulder blades/base of neck)

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c) Area covered by collar and case	The area of both collar and case should be kept at a minimum, identifying an appropriate trade-off between covered area and protrusion	Components should be distributed along the collar to avoid protrusion (derived from computer scientists and cat carers)  Collar should be narrow to minimise the body's area covered but not threadlike
d) Protrusion of the device inner surface in contact with the animal's skin	Eyelets and similar inner protrusions should be avoided	Components should not bulge inward against the neck of the animal (at least).
e) Collar fastening method (e.g. buckle, Velcro straps, etc.)	Buckles and other fastening methods that may catch tufts of fur should be avoided, especially for medium and long-hair cats	Buckles or Velcro strips should be avoided because they could scratch/chafe the skin or pull the hair (derived from computer scientists but in contrast with the other two teams).  Collar should be easy to attach.
f) Case material	Hard materials that might disrupt rubbing should be avoided  Ensuring that any soft materials used are odourless	It must be used a protecting thin coating in turn wrapped by soft and flexible material  Materials that have odours should be avoided (from biologists) to not irritate cats' smell sensitivity
g) Collar material	Low-tension elasticated and frictionless material that fits the neck and avoid the collar to get loose should be preferred	Collar should be made of soft and flexible material to not irritate cats' skin and adapt to the neck form
h) Movement of the collar around the neck	Fastening mechanisms should allow the case to slide along the collar within a restricted range of the nape	-
i) Device weight	-	The device should be as light as possible to avoid extra burden
j) Device colour	-	The device should be blended with the animal's fur colour to avoid disrupting camouflage
k) Components connection	-	Components should be wired together and not communicate wirelessly to avoid unwanted background noise
l) Light spectra /(ultra)sound frequencies	-	Sensory inputs should be avoided to not irritate cats' sensory perception
m) Batteries characteristics	-	Chargeable wireless stations should be preferred to minimise the weight of batteries
n) Aerial's characteristics	-	The aerial should be diffuse all around the collar to allow a reliable



		signal (not dependant from the electronics' position)
o) Safety	-	The device should be easily released if wearers get entangled
p) Device retrievability	-	The device should be somehow retrievable if lost
q) Collar adjustability	-	Collar should be adjustable to the neck size
r) Device visibility	-	The device should be inconspicuous for other animals
s) personalisation	-	Modular adds-on may render the device user personalised and more sellable
Total requirements	Nine (9)	Twenty-two (22)

Table 6.3: Comparison between study-1 and workshop requirements.

As shown in Table 6.3, through study 1, we were able to establish nine wearability requirements. In contrast, the three workshop teams derived twenty-two requirements in total, thirteen of which (List A) were in common across them. In other words, it is evident that the workshop activities - informed by the WCF - produced a larger number and variety of requirements compared to our direct observations with cats.

Next, for each of the design features or qualities listed in Table 6.3, we discuss the extent of equivalence between the two sets of requirements (those empirically derived and those heuristically derived). Then, we draw our conclusion about the suitability of the heuristic process informed by the WCF in establishing wearability requirements consistent with cats' needs, activities, characteristics, and environments.

**Exterior protrusion.** All three teams imagined thin and narrow components distributed along the collar. Piling them up inside a single box was never considered. The cat carers proposed piling up only the electronics together, but they had in mind that the components would have been thin and so their overall thickness would be contained. In principle, this is accordant with the empirical requirement of keeping the protrusion at a minimum. In addition, the designers referred to protrusion at a two-dimensional level, including also that the components' outward protrusion from the surface of the collar should be minimal.

**Position of the case.** The workshops and study-1 requirements for this feature are equivalent, as they both establish that the position of the case should be near the nape, where cats cannot reach it. This does not necessarily mean that the nape is a comfortable position; however, from the direct observations, it seemed to be less disruptive for cats to have the device on the nape, especially when licking the throat.

**Area covered by collar and case.** The computer scientists and the cat carers established that the components should be positioned all around the collar. This implies the use of the whole

collar perimeter. This seems divergent from the corresponding study-1 requirement according to which the area of the case should be kept at a minimum; however, having the components distributed was for designers a way of reducing protrusion, which is in line with the trade-off between covered area and protrusion derived empirically. With respect to the collar, the heuristic and empirical requirements are equivalent since both establish that the collar should be narrow in order to minimise the body's area covered.

***Protrusion of the device inner surface in contact with the animal's skin.*** The designers agreed that any unavoidable protrusion should not bump inwardly against the cats' body. This is equivalent to the study-1 requirement that inner protrusions such as eyelets should be avoided.

***Collar fastening method.*** The computer scientists established that any method to connect the two extremities of a collar could be obtrusive and therefore should be avoided. This corresponds with what was established empirically with regards to avoiding fastening methods that might pull tufts of fur. However, the biologists and the cat carers valued the feature of a mechanism that enables to easily close the collar. Although a device easy to attach would likely reduce the cat's stress induced by attaching procedures, doing this through a locking mechanism might maintain the risk of chafing the skin or pulling the hair. Hence, the two fastening requirements (i.e. avoiding obtrusive methods and having a collar easy to attach) should be carefully considered in juxtaposition with each other.

***Case material.*** For all designers, the case around the electronic components was intended as a thin coat mainly aiming at protecting the electronics from water. Moreover, such a holding layer was intended to be wrapped by a soft and flexible collar. The material used for both case and collar varied across teams; however, all teams specified that it should be soft and flexible. This is equivalent to the study-1 requirement that the use of hard materials should be avoided. The biologists also referred to the need to avoid materials that have an odour, which corresponds to an equivalent empirical requirement.

***Collar material.*** Designers established that the collar should be made of soft and flexible material to allow it to be comfortable and ergonomic, while study-1 requirement specifies that the collar should be elasticated in order to adhere well to the neck but without causing friction on it. Although different in specification, both purposes and qualities of the suggested materials are attributable to good ergonomics and comfortability (being flexible or adherent; being soft or frictionless).

***Movement of the collar around the neck.*** This was a study-1 requirement concerning the cats' need of scratching the area underneath the case. There is no workshop requirement regarding this feature. Indeed, the fact that, for the designers, the components should be distributed around the collar, makes this feature irrelevant, since by sliding the collar that

support evenly distributed components, the area freed from the case is basically non-existent.

Finally, **other requirements** regarding device features such as weight, colour, connection of components, light spectra and (ultra)sound frequencies, batteries' and aerial's characteristics, along with requirements concerning device qualities such as safety, device retrievability, collar adjustability, device visibility, and personalisation were established by the workshop designers but do not have a study-1 requirement to be compared with.

From this requirements comparison, we concluded that a heuristic approach allowed the designers to establish requirements consistent with cats' needs and characteristics, as well as additional requirements that may be important for wearability but that might not be identified through empirical observation alone. Thus, our findings suggest that a heuristic approach informed by the WCF might in fact be more effective than empirical observation approaches. This is supported by the following considerations:

It was possible to obtain a large variety of requirements heuristically (i.e. twenty-two) by means of prototyping activities informed by the WCF.

During the workshops, which were limited in time, space and overall contextual conditions, designers were informed in a way that exceeded the insights obtainable with observations of cat participants.

Several workshop requirements were equivalent to study-1 requirements with regards to the (re-)design of a device feature; for example, there was agreement about what would be the best location for the case, or the protrusion of the case. Moreover, some of the workshop requirements had been articulated in more detail, partly thanks to the collaborative nature of the sessions and partly thanks to the richness of variables that the WCF prompted the designers to consider.

Some of the requirements identified during the workshops were more functional and user-centred than wearer-centred (having a device easy to attach; covering the components with a protecting layer; having a reliable signal; making the device easily retrievable; and personalising the device with adds-on). However, these were few (i.e. five over twenty-two) and, more importantly, the design features that these requirements suggested would lead to improvements benefitting wearability (a device easy to attach would likely reduce the cats' stress induced by attaching procedures; a thin case would minimise protrusion and the need of a hard encase; a threadlike antenna would help reducing the bulkiness of the device; using a GPS signal to retrieve lost devices does not add extra components).

### **6.3 Chapter summary**

This chapter described the application of the WCF during a requirements activity conducted by means of collaborative workshops, providing an answer to the second operative question

of this research about how to use the framework during a design process (*How could the framework be applied during the design process*). The requirements activity aided by the use of the framework ended up with a variety of wearability requirements established by teams of designers concerning features and qualities of a device that are reflected in various WCF dimensions (see Figure 4.1 for reference): non-deleteriousness (e.g. collar should be made of soft and flexible material to not irritate cats' skin); minimisation of effect (e.g. the device should be as light as possible to avoid extra burden); sensory imperceptibility (e.g. materials that have odours should be avoided to not irritate cats' smell sensitivity); cognitive acceptability (e.g. the case should be positioned on the least intrusive place on the cat's body); and significant others (e.g. the device should be inconspicuous for other animals). The chapter also answers partially to the third operative question about how to evaluate the WCF's usefulness (*How could the usefulness of the framework as a design-informing tool for wearability be evaluated?*). The comparison between wearability requirements heuristically-established and the wearability requirements empirically-derived by means of the observational study 1 provides a first validation of the usefulness of the WCF as an enabling tool for the elicitation of requirements consistent with the cats' needs, characteristics, activities, and environments. The overall conclusions of this research phase are that the WCF is a suitable instrument for carrying out a heuristic requirements analysis for wearability. However, although this interpretation is supported by empirical evidence provided by the comparison with study-1 requirements, further validations were deemed necessary. These are provided in the next two chapters (7 and 8). In particular, chapter 7 describes the designing of a prototype derived from the 'heuristic' requirements and reports the testing of such a prototype with cat informants. The aim of the exercise was to provide further empirical evidence of the viability of the WCF as an informing tool for the design of a wearer-centred device, by testing whether the wearer experience (WX) with the prototype improved in relation to the off-the-shelf devices previously tested.

## **7. DESIGNING AND TESTING THE WEARER-CENTRED PROTOTYPE**

The wearability requirements elicited during the workshops and reported in section 6.1.4 were used to design a physical animal-centred prototype which was tested with cat participants, to see whether it afforded good wearability for them. This chapter describes firstly the prototyping activities employed to build the prototype (section 7.1) and then, the tests conducted with cats to assess its wearability, therefore providing the second form of validation of the WCF's usefulness (section 7.2).

### **7.1 Prototyping the cat-centred device**

#### **7.1.1 Rationale, approach and process**

This stage of the research had the aim of designing a prototype derived from the workshops requirements to show that the wearer-centred framework (WCF) could be operationalised and to demonstrate that, by means of it, a design centred on wearers could be achieved. We had two possibilities: to either choose one of the three requirement sets emerged from workshops as a whole or select requirements from all those established by the three teams. We opted for the second option based on the fact that the focus groups were design trials limited by time and participants' competences, therefore each set taken individually was not complete enough (arguably, in a real case scenario, where teams would include multiple expertise, this effect would presumably be much reduced). For example, the set of requirements established by the computer scientists (Table 6.1) missed accounting for features such as an aerial, or aspects such as the emission of light spectra or odour. Therefore, to systematically choose the most appropriate requirements of the three sets for any of the feature or quality listed in Table 6.1, we proceeded as follows. Firstly, we selected all the workshop requirements that were in common across the three teams (from List A in section 6.1.4). Then, where differences applied (i.e. List B and C), we chose one or another team's workshop requirement, depending on the extent to which designers reflected about wearability; that is, if and how teams considered wearability implications and expressed aspects accounted for by the framework. For example, the computer scientists specified that the device should be a unique piece of elasticated material in order to avoid the collar scratching or chaffing the cats' skin, while the biologists and cat carers opted for standard collars to be easily fastened through closing mechanisms. In choosing which kind of collar could achieve a better wearability, we selected the unique-piece elastic band since the computer scientists were concerned about the discomfort that any fastening method could exert anytime on the wearers, while the biologists and cat carers were more worried about the momentary problem of putting on the collar. In other words, the former had a more accentuate wearer-centred perspective than the latter. Looking back at the study-1 requirements, the computer scientists' requirement we chose is consistent with the empirical outcome that fastening methods such as Velcro or buckles should be avoided (see empirical requirement of feature e- in Table 6.3), which further validates our choice.

However, when the differing requirements had equivalent wearability orientation, we opted for any same requirement established across two teams, since we deemed that selecting the same outcome reached independently by two teams would constitute the most objective criterion, due to the inapplicability of the other two criteria. Finally, the workshop requirements identified by only one team (in List B) were directly selected. Schematically, for each feature or quality listed in Table 6.1, the requirements selection approach followed 4 rules:

- 1- Select workshop requirements identified across the three teams (these are summarised in List A);
- 2- If workshop requirements differ across the three teams or are similar across only two teams (these are summarised in List B and C), select the one that expresses greater consideration for wearability issues;
- 3- If workshop requirements are similarly oriented towards wearability, select the one identified across two teams;
- 4- If a workshop requirement is not identified by more than one team, select the one identified by one team.

#### *Limitations of the approach*

This systematic approach to the choice of the requirements was employed to develop a prototype derived as much as possible from designers' insights. However, this led to some prospective flaws in the prototype. In one circumstance, a requirement was selected to adhere to the above protocol (rule 3) even though we thought that another requirement would have been more appropriate. In this example, the biologists were concerned that a wireless charging system could produce heat that could potentially harm the wearer, so the team opted for the removal of the batteries during recharging. Although this is a sensible idea, we stuck with what the other two teams had established in relation to this design feature, that is recharging the batteries wirelessly, since both biologists' requirement and the other two teams' requirement were established with wearability issues in mind: avoiding the device overheating for the biologists, and reducing the burden on the wearer for the computer scientists and for the cat carers.

#### **7.1.2 The prototype**

Following the approach described in the previous section, we sketched the cat-centred prototype illustrated in Figure 7.1. However, when it came to make the actual physical device (Figure 7.2), some of the features were modified in accordance to the resources available to us and the feasibility of implementing what the workshop designers had proposed. This resulted in a prototype that partially differed from the one sketched in Figure 7.1, as discussed below.

### Sketched prototype

As per established by all three teams (see List A in section 6.1.4 and Table 6.2 for reference) the device (Figure 7.1) had to be a narrow built-in collar; not protruding inwardly and minimally protruding outwardly; weighting equally or less than the lightest device on the market; colour blended with individuals' fur; easy to pull out; retrievable; with soft texture; wrapped in a thin waterproof coat; with thin and narrow components distributed along the collar and aligned end-to-end, connected to each other through some conductive material. These requirements were according to rule 1 of the prototyping approach described in section 7.1.1.

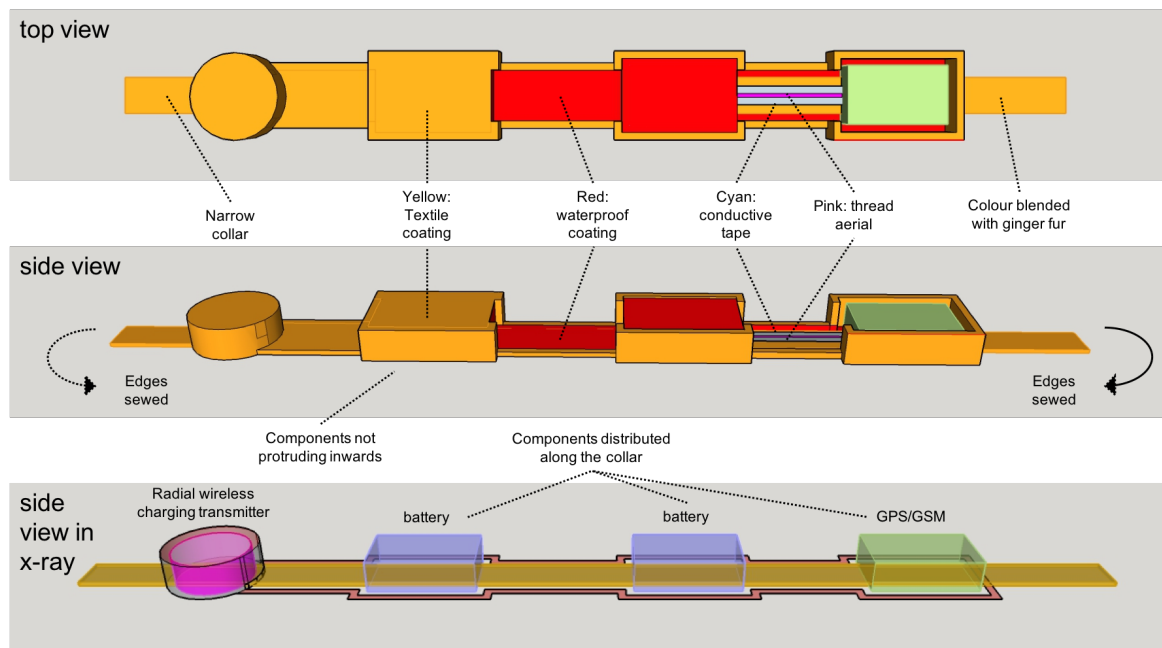


Figure 7.1: The sketched prototype and its components.

Regarding the number and sizes of the technological components, we sketched them relying on the same assets in the PawTrax® Halo tracker tested in study 1, which consisted of two batteries, an integrated GPS/GSM unit, an antenna, and a charging element. As mentioned in chapter 5, section 5.2 (p. 76), at the time of this research, this was the lightest GPS available on the market (weighing 21.7 grams).

Workshop requirements among Lists B and C (section 6.1.4 and Table 6.2 for reference) were selected as follows:

As proposed by the computer scientists' team, we opted for a unique piece of elasticated collar that gets pulled on and off the cat's head without opening and closing the collar extremities. This solution was chosen to avoid fastening mechanisms that might somehow irritate the cat's skin and it is consistent with empirical findings that buckles and Velcro straps might catch fur and prickle hair follicles. This feature also affords safety since a low-tension elastic textile pulls easily off the neck if stretched (this was assumed by the team

and tested with the principal investigator's cat). This design choice followed from rule 2 of the prototyping approach (section 7.1.1).

Although the use of soft and flexible material was established by the three teams, there was no agreement on a specific material. Following the concern from biologists that devices should be odourless (also equivalent to an empirical requirement of feature f- in Table 6.3), we dismissed the use of silicone or rubbery material, which might have strong odours. Instead, we stuck with fabric as proposed by both computer scientists and biologists. Both rules 2 and 3 were followed.

We did not have agreement across teams about how to recharge the batteries with one team (the biologists) proposing that they should be detached when out of power and the other two teams (the computer scientists and cat carers) positing that the cells should be charged wirelessly. Since both detachability and 'wirelessness' were similarly wearer-centred (i.e. to decrease the device's intrusiveness and avoid its impact from overheating), the sketched device was designed to have a radial wireless charger according to what was identified across two teams (i.e. the computer scientists and the cat carers). This followed from rule 3.

Any sound actuator was avoided following the requirement of computer scientists and biologists that acoustic signals should be avoided (consistent with rule 3), and the requirement of the biologists that visual and osmic elements should also be avoided (consistent with rule 4).

The cat carers' team was the only one to address the matter of the antenna, therefore we used their requirement that there should be a threadlike aerial along the collar. This followed from rule 4.

### *Actual prototype*

The actual cat-centred prototype is illustrated in Figure 7.2. Its technological components are those of the dissembled PawTrax® Halo device used in study 1 (as mentioned earlier, these were chosen to keep the collar as light as possible). Specifically, such components were two lithium batteries (3.7 v, 160 mAh), a micro USB port, a switch, a customised GPS/GSM unit and an antenna (from left to right in Figure 7.2a). In the original product, the components were wired together and kept side by side inside two rigid boxes (Figure 7.3). For our prototype, we disconnected and re-wired them together to evenly distribute them and thus allow flexibility (Figure 7.2a). Then, we wrapped the electronics inside a thin waterproof coat (Figure 7.2b) and placed the wrap on a 9mm-width elasticated band, which we covered with a textile (Figure 7.2c). In this way, the elastic band was inserted into the fabric wrap which could slide along it. Finally, the two elastic band's edges were sewed together to make a collar (Figure 7.2d) and the seam was slid under the textile cover in order to hide any discontinuity of the band's inner line that might prickle the skin. Although the prototype was not a working device, using real components was deemed important to



simulate as much as possible features such as the weight and size of a real device that would matter from the perspective of the wearer. Figure 7.2e shows the prototype attached to a real-size stuffed cat toy (the same dummy cat used during the workshops).

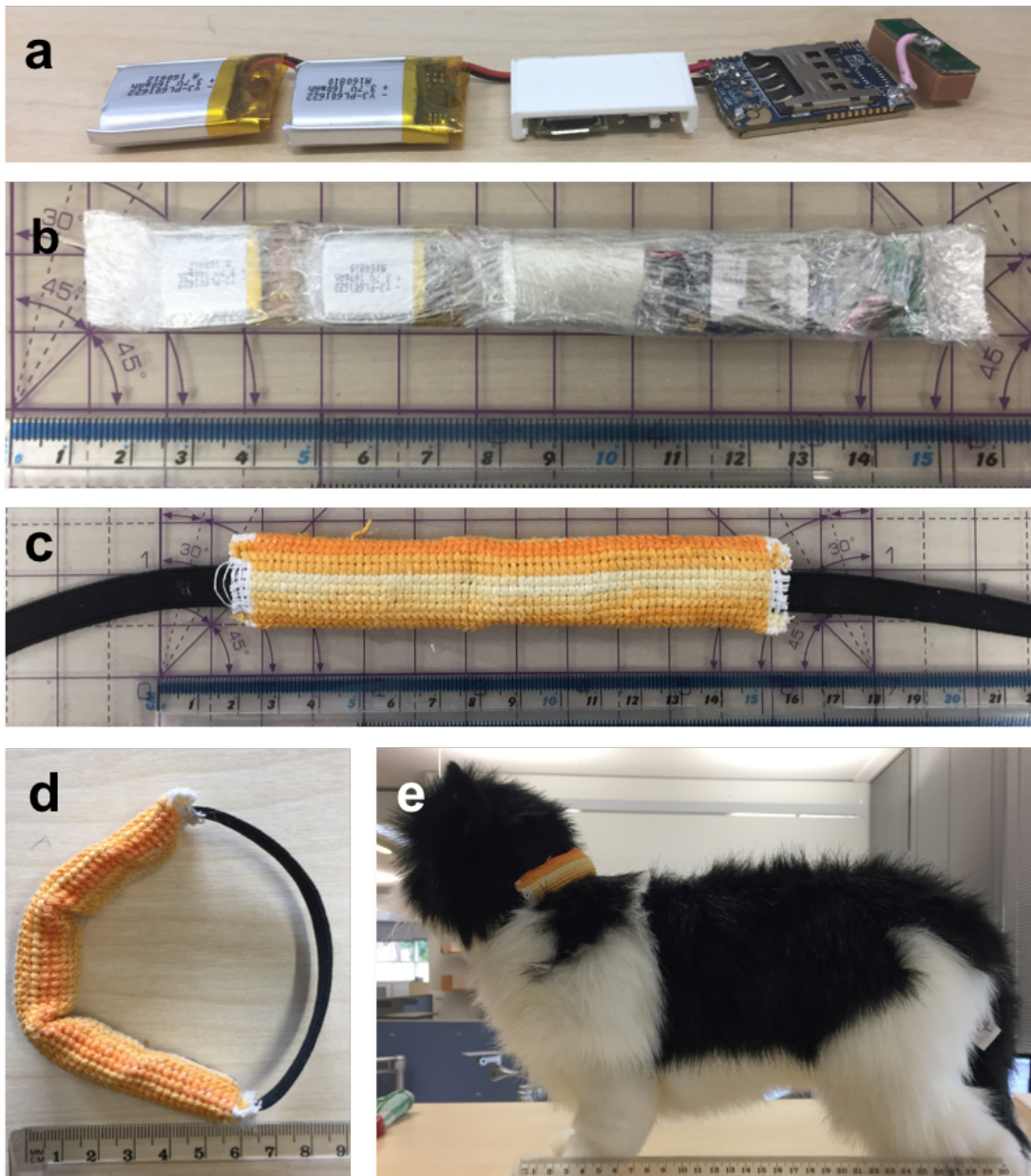


Figure 7.2: The actual prototype – a) the components wired together to allow flexibility, b) the components wrapped inside a thin protecting layer, c) the wrap is covered with textile, d) the completed prototype, e) the prototype worn by a stuffed cat.

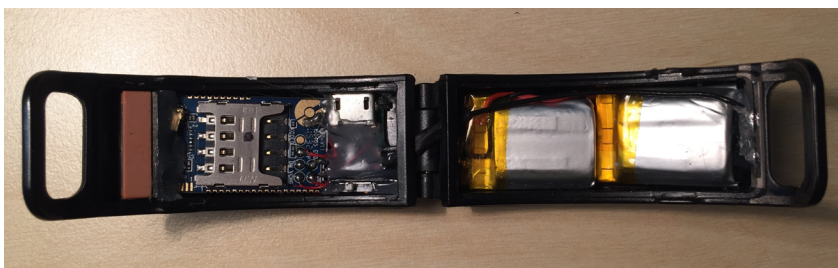


Figure 7.3: Inner disposition of the PawTrax components.

When designing the actual prototype, we tried to follow as much as possible the sketch in Figure 7.1. We implemented the concept of a built-in collar made of a soft and stretchy textile; adopted the solution of an unclasped collar in the shape of a hoop; kept the overall device as narrow as possible by choosing a narrow elasticated band; coated the electronics with a thin protecting film; distributed the components along the band as much as possible and minimised their inner protrusion. However, due to feasibility issues that emerged while making the collar, we had to trade-off the following features:

The idea of having the component spread at equal intervals all around the collar had to be modified due to the difficulty of crafting a complex stretchy design. For example, we could not find stretchy but resistant conductive material to connect the electronics such as coiled or elasticated wires, or elasticated conductive tape, or conductive ink resistant to pulling stress. Hence, we used normal wires to connect all the parts together, resulting in a narrower distribution of the components contained in a flexible but non-stretching section, connected to a ‘naked’ elastic band that provided the stretchy function.

We did not have the availability of a threadlike aerial. Thus, we used the rectangular one obtained from the PawTrax device disassembled.

The wireless charging transmitters available to us were too big and heavy to accord with the requirements of keeping weight and size of the device at a minimum. Thus, we opted for a standard mini-USB charging port.

The resulting device was then evaluated with cats in study 2, as reported in the next section.

## **7.2 Wearability test of the prototype: Study 2**

The physical prototype derived from the workshop requirements and described in the previous section was tested with feline participants in a wearability study aiming at observing which behavioural patterns described in study 1 were still performed by the cats while wearing the prototype.

In study 1, thirteen cats were observed while wearing off-the-shelf devices (chapter 5). Their behaviours were recorded and analysed to measure behavioural indicators of discomfort and to detect flaws in the physical design of the devices. Scratching, shaking, and episodes of active interactions were identified as behaviours that show an extent of device-induced discomfort, while environmental, contextual, and species or breed-specific factors were annotated as providing design-related information; these behaviours and activities were previously reported in Tables 5.7, 5.9, 5.10, and 5.11, and are summarised in the following Table 7.1.

<b>Scratching</b>	Double scratching on the same spot of the neck/throat performed repeatedly; Scratching insistently (i.e. for more than 6 seconds); Repeated scratching performed in alternation on both sides of the neck; Scratching the case or collar of the device; Scratching where the buckle is (nape)
<b>Shaking</b>	Increment of shaking during device (regardless if performed consecutively, forcefully, repeatedly, or while walking)
<b>Active interaction</b>	Cuffing the case with forepaws while standing on hind legs Actual lick of the case Attempt to strike a forepaw at the collar region Attempt to bite the case Licking the collar area Actual bite of the case Head rolling
<b>Environmental, contextual, species/breed-specific factors</b>	Rolling the body on the floor Sniffing objects Rubbing against objects, floor, others

*Table 7.1: Behaviours showing device-induced reactions as per found in study 1.*

These same behaviours were measured again in study 2 with two of the thirteen cats who had participated in study 1.

### *Rationale*

This test was primarily intended as an indirect evaluation of the WCF; that is, because the requirements used for prototyping were derived from the application of the WCF, if the resulting prototype achieved better wearability for cats in comparison with the previously evaluated off-the-shelf devices, this would provide evidence to suggest that the WCF could indeed inform good wearability.

Additionally, although the WCF was developed to allow for an early requirements analysis and thus delay a direct involvement of prospective wearers, later stages of the design process require such involvement as a way to fully understand animal wearability. Thus, testing the

prototype was consistent with the (animal) interactor-centred design process that this thesis proposes, which – drawing from UCD – acknowledges the importance of involving interactors as informants at some point in the design process.

### *Participants*

As mentioned above, we selected the participants for study 2 among the thirteen cats who had participated in study 1. The selection criterion was driven by the compromise between the necessity of acquiring the perspective of animals directly from them and the need of minimising their involvement. Hence, we selected the minimum number of cats that had covered the whole list of behaviours reported in Table 7.1. In practice, we listed all the behaviours performed by each cat in study 1 as reported in Table 7.2. Firstly, we identified the cats representing the widest range of behaviours; these were C6 and C10 with 12 behaviours each, although only C10 was available for re-testing. We thus considered other cats who had performed the behaviours not performed by C10. C13 was the only cat who attempted to strike a forepaw at the collar region. Both C4 and C9 scratched the collar buckle on their nape, but C4 showed a greater variety of discomfort behaviours. Finally, cuffing the case with forepaws while standing on hind legs was performed by C6 and C7, but C6 was unavailable for a re-test. Following this selective process C10, C13, C4 and C7 were selected as representative cats. However, at the last minute, C7 and C13's carers withdrew from the study (for unrelated reasons), so we carried out study 2 with C4 and C10. In Table 7.2, the behaviours the cats represented are highlighted in grey and the identifier of the cats that were ultimately selected for re-testing are highlighted in bold.

<b>Cat ID</b>	<b>Behaviours (device) – n. of behaviours</b>
C1	Licking the case (T), scratching insistently (i.e. for more than 6 seconds) (T), scratching the case or collar of the device (T) – <u>3 behaviours</u>
C2	No behaviour of interest
C3	Double scratching on the same spot of the neck/throat performed repeatedly (P), scratching insistently (i.e. for more than 6 seconds) (P), scratching the case or collar of the device (P) – <u>3 behaviours</u>
<b>C4</b>	Licking the collar area (T), double scratching on the same spot of the neck/throat performed repeatedly (P+T), scratching insistently (i.e. for more than 6 seconds) (P+T), repeated scratching performed in alternation on both sides of the neck (P), scratching the case or collar of the device (P+T), <b>scratching where is the buckle (nape)</b> (T), attempt to bite the case (T), head rolling (T), rubbing against objects, floor, others (T) – <u>9 behaviours</u>
C5	No behaviour of interest

C6	Licking the case (T), licking the collar area (T), scratching insistently (i.e. for more than 6 seconds) (T), scratching the case or collar of the device (T), scratching where is the buckle (nape) (T), attempt to bite the case (T), actual bite of the case (T), head rolling (T), cuffing the case with forepaws while standing on hind legs (T), rolling the body on the floor (T), sniffing objects (P+T), rubbing against objects, floor, others (T) – <u>12 behaviours</u>
C7	Licking the case (T), licking the collar area (P+T), double scratching on the same spot of the neck/throat performed repeatedly (P), scratching insistently (i.e. for more than 6 seconds) (P), repeated scratching performed in alternation on both sides of the neck (P), actual bite of the case (T), head rolling (T), cuffing the case with forepaws while standing on hind legs (T), rolling the body on the floor (P+T), rubbing against objects, floor, others (T) – <u>10 behaviours</u>
C8	Scratching insistently (i.e. for more than 6 seconds) (P), repeated scratching performed in alternation on both sides of the neck (P) – <u>2 behaviours</u>
C9	Double scratching on the same spot of the neck/throat performed repeatedly (P+T), scratching insistently (i.e. for more than 6 seconds) (P), repeated scratching performed in alternation on both sides of the neck (P), scratching the case or collar of the device (P), scratching where is the buckle (nape) (T) – <u>5 behaviours</u>
<b>C10</b>	<b>Licking the case (T), licking the collar area (T), double scratching on the same spot of the neck/throat performed repeatedly (P+T), scratching insistently (i.e. for more than 6 seconds) (P+T), repeated scratching performed in alternation on both sides of the neck (P), scratching the case or collar of the device (P+T), attempt to bite the case (T), actual bite of the case (T), head rolling (T), rolling the body on the floor (T), sniffing objects (P+T), rubbing against objects, floor, others (T) – <u>12 behaviours</u></b>
C11	Licking the collar area (T), scratching the case or collar of the device (T), rubbing against objects, floor, others (T) – <u>3 behaviours</u>
C12	Scratching insistently (i.e. for more than 6 seconds) (P+T) - <u>1 behaviours</u>
C13	<b>Attempt to strike a forepaw at the collar region (P), rubbing against objects, floor, others (T) – <u>2 behaviours</u></b>

Table 7.2: List of behaviours performed by each cat during study 1. Tractive (T) and PawTrax (P) indicate with which device the behaviours were performed. In bold: the behaviour indicative for the cat participating in study 2.

### 7.2.1 Protocol and data analysis

C4 and C10 were each fitted with the prototype for 6 continuous hours during a day and observed following the same observational technique employed in study 1 (20 minutes of continuous recording every hour for each of the 6 hours). For C4 and C10 respectively, we counted the occurrences of licking strokes at the collar region, scratching, and head/body shaking performed during the recorded period employing the all-occurrences sampling technique (section 3.4.3); then we put in relation the frequencies of the recorded behaviours with those recorded for the same cats in study 1. We also counted the active interactions that C4 and C10 had respectively performed in study 1, recording them as a binary score (i.e. following a one-zero sampling technique for any behaviour listed in Table 7.1 – shaking excluded, since it was determined as a pure quantitative indicator – section 5.5.1). For example, in study 1, C4 had performed the behaviour of scratching the nape while wearing the Tractive device; hence, we noted whether he performed the same behaviour in study 2 while wearing the prototype. If he did, we counted one, otherwise we counted zero. We did not consider environmental, contextual, and species or breed-specific factors, per se, as indicating discomfort. However, we reported them with reference to the triggering of a potential response. For example, if C4 rubbed his body against something and this stimulated a response (e.g. scratching or body shaking), we considered that the device might produce a level of discomfort. With this quantitative analysis, we sought to understand the extent to which the prototype afforded improved wearability in relation to the off-the-shelf products tested in study 1. When comparing the results obtained from the test of the prototype with those obtained from study 1, we used the same convention described in section 5.4 (p. 85), according to which ‘equal’ refers to the same number of occurrences across devices, and ‘similar’ refers to whether the difference is more than zero but no more than three.

Additionally, we annotated further information that we deemed important for the wearability of the prototype.

### 7.2.2 Findings

Two types of outcomes are reported in this section: measures of the behaviours (corresponding to those performed by the cats during study 1), and further annotations regarding the design of the prototype.

#### *Measures of behaviours*

Figures 7.4 and 7.5 show the number of occurrences for licking, scratching and head/body shaking registered for C4 and C10 respectively while wearing the prototype, the PawTrax, and the Tractive devices.

Tables 7.3 and 7.4 list the individual reactions that in study 1 were found to be important for measuring wearability for each of the two cats.

While wearing the prototype, C4 never licked the collar area. This was equal to PawTrax and similar to Tractive. Regarding the scratching behaviour, this participant decreased it while wearing the prototype (i.e. 5 times) in comparison with both PawTrax (i.e. 9 times) and Tractive (i.e. 21 times). He also decreased his head/body shaking (i.e. 11 times) compared to PawTrax (i.e. 20 times), although the behaviour's occurrence was similar in comparison to Tractive (i.e. 12 times) (Figure 7.4).

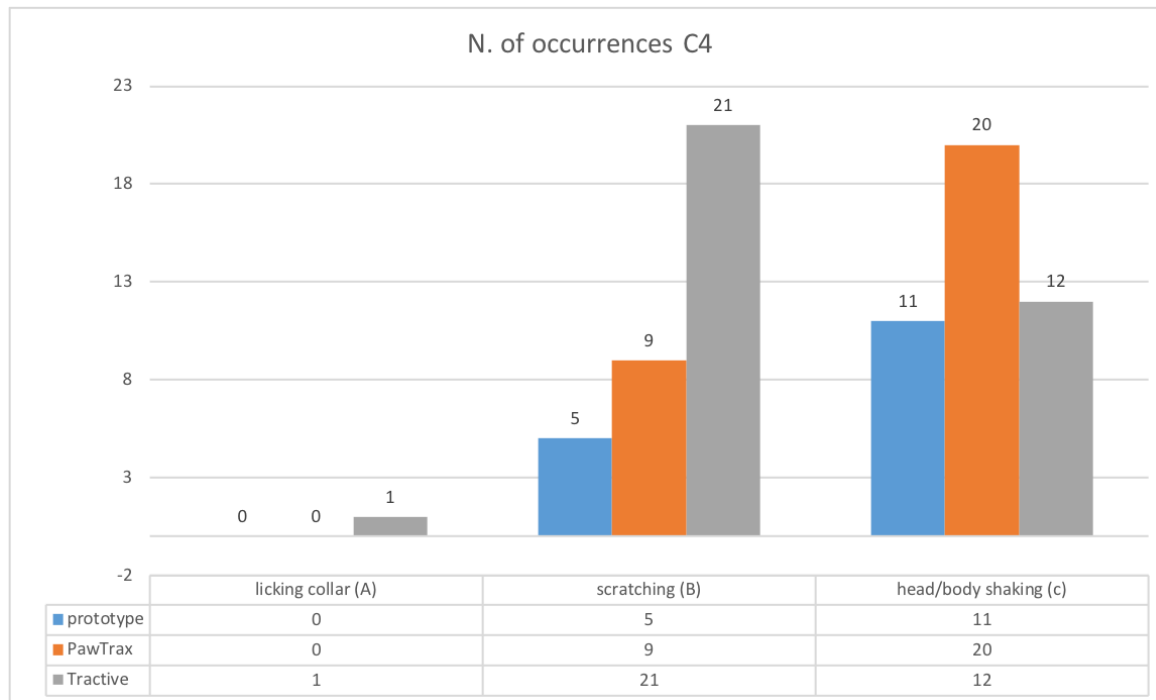


Figure 7.4: Occurrences of licking the collar area, scratching and head/body shaking in C4 while wearing the prototype, the PawTrax, and Tractive devices.

Of the nine behaviours that C4 performed with the off-the-shelf devices (Table 7.2), he performed only three of them while wearing the prototype (Table 7.3): he scratched the case of the device, scratched the nape, and rubbed against house furniture. However, this last behaviour did not trigger any other response, therefore it was surmised that the prototype did not disrupt rubbing.

Behaviours for C4		Yes/No
1	Double scratching on the same spot of the neck/throat performed repeatedly (P+T)	No
2	Scratching insistently (i.e. for more than 6 seconds) (P+T)	No
3	Repeated scratching performed in alternation on both sides of the neck (P)	No
4	Scratching the case or collar of the device (P+T)	<b>Yes</b>
5	Scratching where is the buckle (nape) (T)	<b>Yes</b>

6	Attempt to bite the case (T)	No
7	Licking the collar area (T)	No
8	Head rolling (T)	No
9	Rubbing against objects, floor, others (T)	<b>Yes</b>

Table 7.3: Type of scratching, active interaction, and contextual, environmental and specie-specific activities performed or not performed by C4 while wearing the prototype. T and P indicate with which device the behaviours were performed.

While wearing the prototype, C10 licked the collar area once, decreasing the behaviour with respect to Tractive (which he licked 4 times) while the behaviour's occurrence was similar to PawTrax. C10 also decreased the scratching behaviour with respect to PawTrax (i.e. 11 times against 18) but increased it in comparison with Tractive (i.e. 11 times against 5). Head/body shaking frequency slightly decreased with respect to both PawTrax and Tractive (i.e. 14 against 18 times for each of the commercial products) (Figure 7.5).

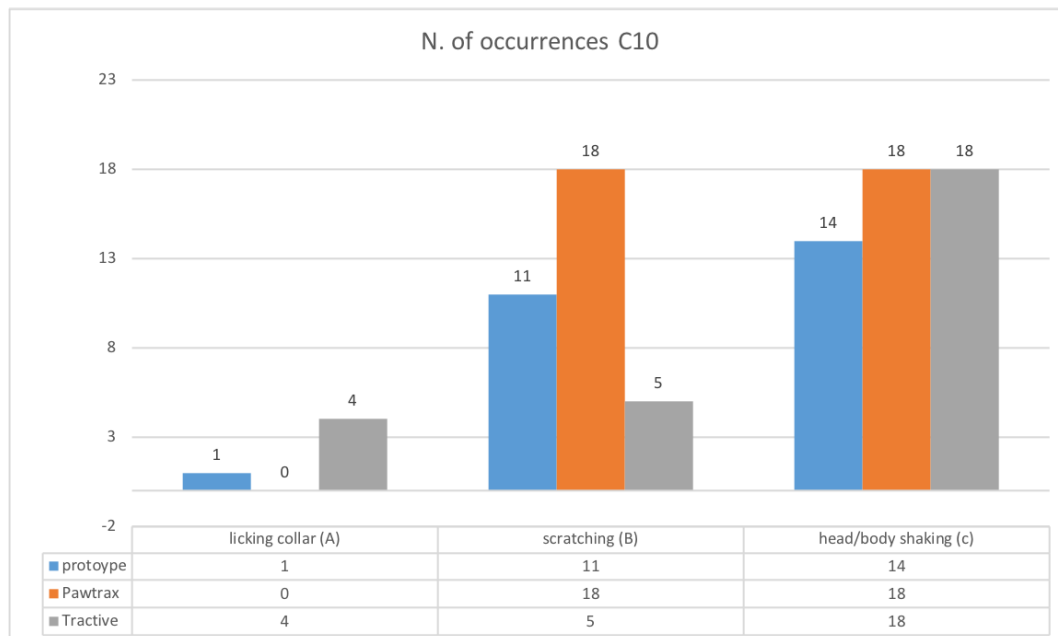


Figure 7.5: Occurrences of licking the collar area, scratching and head/body shaking in C10 while wearing the prototype, the PawTrax, and Tractive devices.

Of the twelve behaviours that C10 performed with the off-the-shelf devices (Table 7.2), he showed five of them while wearing the prototype: he scratched repeatedly the same spot of the neck, scratched insistently (i.e. for more than 6 seconds), scratched the case of the device, licked the collar area with single strokes, and sniffed around (Table 7.4).

Behaviours for C10		Yes/No
1	Double scratching on the same spot of the neck/throat performed repeatedly (P+T)	<b>Yes</b>
2	Scratching insistently (i.e. for more than 6 seconds) (P+T)	<b>Yes</b>



3	Repeated scratching performed in alternation on both sides of the neck (P)	No
4	Scratching the case or collar of the device (P+T)	<b>Yes</b>
5	Licking the case (T)	No
6	Attempt to bite the case (T)	No
7	Licking the collar area (T)	<b>Yes</b>
8	Actual bite of the case (T)	No
9	Head rolling (T)	No
10	Rolling the body on the floor (T)	No
11	Sniffing objects (P + T)	<b>Yes</b>
12	Rubbing against objects, floor, others (T)	No

*Table 7.4: Type of scratching, active interaction, and contextual, environmental and specie-specific activities performed or not performed by C10 while wearing the prototype. T and P indicate with which device the behaviours were performed.*

#### *Further annotations*

As a further annotation, there was an important observation regarding the ease of putting the stretchy collared prototype on the two cat participants in study 2 (plus other three cats of the principal investigator with whom the kind of attachment was tested before conducting the study): it was easier and quicker to put the elasticated collar through the cats' heads than placing the collar around the neck and then attaching its two extremities, as the commercial products in study 1 required. Pulling the elasticated hoop and sliding it over the head was a two-movements operation, quick to perform. Cats did not need to be held and remained in their resting position during the fitting process. In practice, they were either sitting or lying on their bellies, and did not move while the experimenter was fitting the prototype collar. In contrast, when fitting the off-the-shelf devices' collars, the thirteen participants of study 1 reacted with individual responses such as sneaking, crouching, retracting their head or rolling it to look at what was happening, or hitting the approaching human hands with a paw. These behaviours could have been triggered by the way in which the experimenter approached, or by the extra time needed to close the buckle or to attach the Velcro strips at the right collar's length, operations rendered more difficult by the hair tufts that could get caught in the fastening mechanism.

However, putting on the prototype was easier than pulling it off. When it was put on, the cats' ears naturally retracted, favouring the required sliding movement. However, when pulled off, the ears obstructed the sliding movement, so that the elasticated collar had to be

stretched further. Nevertheless, the cats allowed us to take off the collar without any particular reaction, which suggested they were not particularly affected.

### **7.2.3 Discussion**

The aim of this study was to investigate whether the wearer-centred prototype afforded a better wearability than the off-the-shelf devices tested in study 1. We conducted this investigation by measuring all-occurrences of the three indicators of discomfort identified during study 1 and by counting whether each cat participant had or not the same individual response towards the prototype as per Tables 7.3 for C4, and 7.4 for C10.

We assumed that the absence of active interactions and lower scores of licking, scratching, and head/body shaking would mean that a device affected the wearer less. Study 2 showed a decrease in the occurrences of behavioural indicators of discomfort, including the absence of many of the reactions directly addressed toward the devices during study 1. In particular, with the exception of the scratching frequency for C10 in relation to the Tractive, both cats showed a decrease of the behaviours indicating discomfort, as well as the presence of only few of the various reactions listed in Tables 7.3. and 7.4 (three over nine for C4, and five over twelve for C10). Importantly, one of the three contextual behaviours performed by C4 was rubbing against objects; this particular behaviour did not trigger any other particular reaction in C4. This might indicate that a soft device, when rubbed against a surface, does not irritate the cat.

These outcomes suggest that the prototype provided a better wearer experience (WX) for the cats compared to either the Tractive or the PawTrax. Since the wearability features of the prototype were designed by means of the WCF, this provides empirical evidence indicating that the framework is able to inform better design for wearability.

However, although these results suggest that the prototype is less disruptive than the commercial products tested in study 1, such a wearer-centred device still had flaws that will need to be addressed in future iterations. In particular, in most of the scratching bouts, both C4 and C10 hit the fabric case with their claws (the peculiar noise could be heard by the observer, though muffled compared to the noise produced against the plastic case of the commercial tags tested in study 1). Although this did not trigger active interactions, such as head rolling or attempts to bite the device (as in study 1), the problem remains that the device prevents the cat from reaching the skin underneath the collar to relieve the itch it may be causing (as described when discussing the flaws of the devices used in study 1 – see section 5.4.2, p. 89). This is probably the reason why C10 performed repeated double scratchings on the same spot of the neck, some of which lasted more than 6 seconds (as he did while wearing the PawTrax during study 1). Indeed, the prototype's external encasement has a similar length and width to that of the PawTrax case because, instead of featuring both narrow and wide segments interspersed along the whole perimeter as per the sketched prototype (Figure 7.1), our prototype still featured an elongated case similar to the PawTrax

box. We already accounted for the fact that this was a practical limitation of our design when we described the actual prototype in section 7.1.2 (*“having the component spread at equal intervals all around the collar had to be modified to comply with the difficulty of crafting a complex stretchy design. [...] [This] resulting in a narrower distribution of the components contained in a flexible but non-stretching section, connected to a ‘naked’ elastic band that provided the stretchy function”* (p. 125)). Although within this research it was not possible to test the sketched solution, the fact that we observed the same issue we observed with the PawTrax further supports the need for a future prototype to feature the slimmest case possible and suggests that a design featuring evenly distributed components would have avoided the problem. We come back on this point in chapter 9, when discussing limitations and future iterations of the prototype.

Another important comparison to be drawn between the behaviours annotated in study 1 and study 2 regards the fact that neither C4 nor C10 scratched both sides of the neck in alternation. In section 5.5.1 (p. 96), this behaviour was attributed to the possibility that the two distal eyelets that hold the PawTrax’s collar exerted a pressure or caused an itch on both sides of the cats’ neck. The prototype was seamless and without inner protrusions, hence the absence of alternated neck scratching supports the validity of the design requirement according to which the surface in contact with the animal skin should be kept as smooth as possible.

Regarding the attachment method, we deemed important the apparent lack of reaction that cats had when we passed the stretchy prototype over their heads. This method rendered the fitting procedure quick and straightforward. In comparison, when attaching the PawTrax and Tractive collars, we experienced mild initial avoidance reactions, such as retraction of the head or crouching (eventually, every cat in study 1 was fitted only after they became confident enough to accept the device). The ease with which it was possible to attach a stretchy collar such as our prototype may be attributed to three factors that may influence the cats’ behaviour: 1) the body’s pose of the person who attaches the collar with respect to the cat, 2) the movement of the person’s hands when the collar is inserted, and 3) the speed of the operation. We realised that in order to pass a stretchy hoop over the cats’ heads the experimenter was able to face the cat, so that *their* hands remained visible to the cats, and likely the whole operation resembled a head stroke to which domestic cats are used. Additionally, the stretchy collar was very quick to fit. In contrast, attaching the two collars edges of both PawTrax and Tractive required the experimenter approaching the cat either from behind or from a side, with *their* hands more likely operating outside the visual field of the cat. This is likely why the cats showed a range of reactions from fleeing to retracting or tilting their head, all behaviours that complicated the operation, which in turn required the experimenter to either hold the cat or abort the fitting and restart later (with the cat now alerted to the fact that the same unpleasant experience might occur again). Moreover,

buckling-up or precisely Velcroing the ends of the off-the-shelf devices took longer and was further complicated by the presence of hair.

To appreciate the extent of discomfort encountered by cats during the fitting of the off-the-shelf devices, it is important to consider that cats do not like unpredictability and for them it is important to have a degree of control over their environment (Rochlitz 2005). Being approached and handled from behind is an unpredictable and not controllable situation for them, comparable to an ambush. A face to face approach allows them to see movements, predict intentions, and exert some control over the situation. This probably increases their confidence towards a human approach. For example, domestic cats are familiar with carers who stroke their heads (and in a good human-cat relationship, they seem to also enjoy it). Being able to see the experimenter's hands getting close to their heads may have reassured them that a familiar and enjoyable stroke was going to be experienced.

Our overall conclusion is that the prototype-kind of attachment, and the fitting procedure that this allows, influenced the behaviour of the experimenter who attached the device, which in turn influenced the cats' behaviour by reassuring them.

### **7.3 Chapter summary**

This chapter firstly described a prototyping stage whose outcome was a cat-centred prototype built using the requirements established heuristically by designers who applied the WCF during a design process. Then, it reported on a wearability test of this prototype, which aimed at validating the usefulness of the WCF as an informing tool for good wearability indirectly, that is through the product of its application. The results of this study suggest that the prototype provided improved wearability compared to the off-the-shelf devices previously tested and, therefore, it supports the conclusion that the WCF can enable designers to achieve good wearability in animal biotelemetry. The study also produced insights into what would need to be improved during the next prototype iteration, foreseen as future work following this research. While testing the framework-derived prototype with cats was an empirical and indirect form of validation of the WCF's usefulness, the next chapter 8 reports on the analytical and direct counterpart (i.e. analysing the designers' dialogues), thus completing the overall answer to the operative question 3 (*How could the usefulness of the framework as a design-informing tool for wearability be evaluated?*).

## 8. EVALUATING THE USEFULNESS OF THE WCF WITH DESIGNERS

In chapter 6 (section 6.2), the requirements resulting from the workshops were compared with the requirements identified during study 1 to evaluate the extent of equivalence between the heuristic and the empirical approach to requirement analysis. In chapter 7 (section 7.2.3), cats' behaviours performed while wearing the two off-the-shelf devices (study 1) were put in relation with those observed while the cats wore the prototype (study 2). In this way, we determined whether the cats' wearer experience (WX) with the prototype improved with respect to their WX with the off-the-shelf devices and, thus, we evaluated whether the prototype achieved wearability in relation with the two commercial products tested in study 1. In turn, this allowed us to assess to what extent the application of the WCF contributed to good wearability, since the prototype was designed based on the requirements established through its use during the workshops. As a further evaluation of the WCF, the designers' discussions recorded during the workshops were analysed thematically to investigate whether and to what extent the designers engaged with the WCF and were informed by it. This chapter presents the approach, process and outcomes of this analysis. It then discusses the role of the framework as an informing tool for wearability.

### 8.1 Rationale

Recalling Blackwell and Green (2003) (section 1.3), the direct recipients<sup>36</sup> of the WCF are designers who might use it to carry out wearer-centred design activities both in a creative and in a systematic fashion. To assess whether the designers participating in the workshops made use of and were informed by the WCF, we analysed the dialogues recorded during the workshop activities. In particular, we looked for the designers' direct and indirect references to the framework and its components. This was an evaluation of the WCF usefulness made through a primary-source material (i.e. directly based on the workshops designers' words), and it served as a further validation of the framework, along with the validation of the workshop requirements (section 6.2) and the evaluation of the resulting prototype's wearability (section 7.2).

### 8.2 Approach: Thematic analysis

The three collaborative requirements workshops discussed in chapter 6 were recorded with video-audio aids and the recorded participants' conversations were transcribed verbatim for analysis. From the dialogues, we firstly extrapolated wearability requirements established by designers (see section 6.1.4), and then, we analysed the conversations to understand whether the designers made use of the WCF and, in this case, whether their thinking was informed by it to align with the animals' perspective. Hence, to evaluate the usefulness of the WCF (i.e. whether the WCF helped designers to account for animal

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<sup>36</sup> Designers might use the WCF for the advantage that the framework helps them to deliver a wearer-centred design; however, animals are the indirect recipients as they benefit from the implementation of a wearer-centred design (see sections 1.4, 3.1, and 6.1.1).

stakeholders' needs and whether they applied the principles, values and concepts provided by the WCF - see footnote 16 (p.43) in chapter 3 for a definition of usefulness), we conducted a thematic analysis (Braun & Clarke 2006) to make sense of the designers' conversations.

As described in *group a* of section 3.4.2, we took six preliminary decisions prior to the analysis as proposed by Braun and Clarke (2006); these are summarised in Table 8.1.

Step 1a	Clarifying what is a theme
Step 2a	Determining what to describe (whole data set or particular aspects)
Step 3a	Reporting the kind of approach (inductive, deductive or abductive)
Step 4a	Deciding the level of interpretation (semantic or latent)
Step 5a	Choosing the epistemology
Step 6a	Clarifying the questions or focus that guides the coding

Table 8.1: The six preliminary steps to take in order to carry out a thematic analysis.

As for step 1a, themes of interest for us were patterns in the segments of transcripts that answered the following questions (step 6a): *Did the designers engage with the WCF? Were the designers informed by the WCF?* Such specific questions drove an initial deductive thematic analysis (step 3a) in which the dialogues were coded with a theoretical framework in mind (i.e. the analysis was pre-set by the questions). This means that a realistic epistemology was chosen (step 5a). To address the questions, we looked into the dialogues for both direct and indirect references to the WCF and its components. Specifically, this was an analysis at a semantic level (step 4a). As for semantic themes, we looked at explicit meanings of the designers' words (i.e. what designers actually said) rather than anything inferred, analysing exactly what participants said when directly or indirectly referring to the WCF and its components. An example of direct reference was when designers named the WCF or (a) component(s) during a discussion; for example, referring to the dimension 'Interactors' in the WCF, a designer stated: "*this is for getting us in the context*" (participant 9 of team 3 (P9, T3)). For indirect reference we mean when designers discussed a dimension that we deemed elicited by the WCF, although the WCF or its components were not named; for example, "*Is there an area on the cat's body that gets touched least from other animals*" (participant 2 of team 1 (P2, T1)). This was a segment of dialogue that did not directly name the dimension called *significant others* in the WCF, but indirectly refers to it.

Because we initially took a deductive approach at a semantic level, we described particular aspects extrapolated from the data set (step 2a); that is, we did not code line-by-line every piece of transcript, but we focused on those dialogues that referred both directly and indirectly to the WCF and its components in order to answer the driving questions: Did the designers engage with the WCF? Were the designers informed by the WCF? (Maguire and

Delahunt 2017). However, while coding, we appreciated that some designers' ideas were more likely elicited by personal experience and knowledge, rather than the WCF. For example, P7 and P8 of T2 exchanged their thoughts: "*as you are a cat owner, how easy is to take stuff from the neck of the cat, to take the collar off and charge it*" (from P8). "*I would prefer to leave it so that the cat gets used to it*" (from P7)". The idea here is to habituate the cat to a device, which is not a WCF's dimension and, actually, can be read as inconsistent with the basic principle of Interaction Design that underpins the WCF, according to which it is the technology that should be adapted to the user (Wickens et al. 1998). Dialogues expressing ideas that were either in contrast with the WCF dimensions or able to add information that can improve subsequent versions of the wearer-centred framework were inductively coded while reading. Thus, although the coding process started deductively by following a pre-determined scheme, the overall approach to coding was abductive, though with a main deductive component.

### 8.3 Process: Conducting the analysis

The thematic analysis was carried out by following the Braun and Clarke's six-phases scheme to thematic analysis reported as *group b* in section 3.4.2 and summarised in Table 8.2.

Step 1b	Acquiring familiarity with the data corpus
Step 2b	Generating preliminary codes from early ideas
Step 3b	Interpreting the codes and searching for themes
Step 4b	Reviewing the themes
Step 5b	Defining what themes are saying
Step 6b	Writing-up about the meaning of the themes

Table 8.2: The six steps for carrying out a thematic analysis.

Firstly (step 1b), we transcribed and read the transcripts in order to be familiar with all three workshops dialogues. While reading, we annotated early impressions and highlighted with different colours relevant parts of transcripts. For example, orange was used for sentences to be used to extrapolate technical details and wearability requirements during the requirements analysis (see section 6.1.3: Data collection and analysis, p. 108); green was used for sentences to be used in the thematic analysis.

Secondly (step 2b), we started coding the segments of transcripts by using an analytic software (NVIVO version 11). We did not code every chunk of the transcripts, but only those relevant to understanding whether the designers used the WCF and were informed by it (i.e. answering the questions guiding the analysis). Although this was a deductive analysis driven by pre-defined ideas, we did not have pre-determined codes. Thus, having the questions to

guide us, codes were firstly generated from what the relevant dialogues expressed, and then revised, in a process defined as *open coding* by Maguire and Delahunt (2017). For example, as mentioned above, P2 of T1 asked the expert: “*is there an area on the cat’s body that gets touched least from other cats?*”. We deemed that the participant was informed by the box of *interactors* of the WCF and that, by directly asking the expert in the room, P2 made use of the *knowing-the-species* box of the framework (Figure 8.1). Hence, this passage was selected and open coded both as *considering the sociality/interaction with other cats* and as *questioning the expert*. Instead, with respect to the inductive part of the analysis, we coded while reading those designers’ ideas that were out of the initial focus determined by the driving questions. For example, P7 and P8’s aforementioned dialogue: “*as you are a cat owner, how easy is to take stuff from the neck of the cat, so take the collar off and charge it*”, “*I would prefer to leave it so that the cat gets used to it*” was inductively coded as: *questioning a cat owner participant*; *habituation of cat to device*; and *need to detach the device for charging* - none of which were dimensions of the WCF.

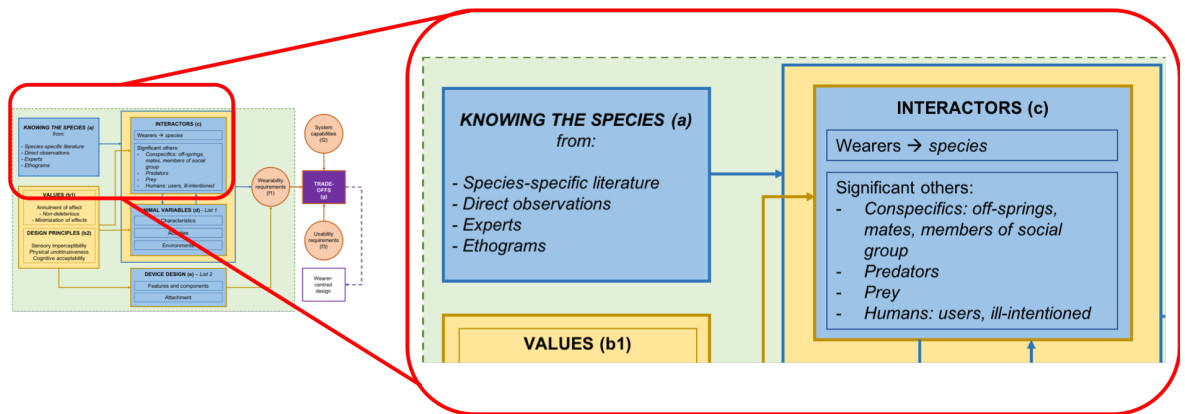


Figure 8.1: The boxes ‘knowing the species’ and ‘interactors’ were deemed to inform Participant 2.

Thirdly (step 3b), after all the chunks of relevant transcripts were coded and the initial codes were revised (e.g. removing, refining, merging, splitting them), the final codes were examined to search for themes (that is, looking for patterns derived from codes that have a common meaning). For example, several of the codes that we extrapolated from the transcripts reflected different variables of cats’ characteristics, activities, and environments; these codes together formed a temporary theme that we named *animal variables discussed by designers*. Some codes served to search for more than one theme, since they related to several patterns. For example, the code ‘*need to minimise device-induced stimulation*’ partly related to the initial themes ‘*discussion about deleteriousness*’ and partly to ‘*considering perception*’ - thus, the code was interpreted as relating to both initial themes.

Fourthly (step 4b), the preliminary themes were reviewed (e.g. modified, aggregated, deleted, moved) to see whether the segments of dialogues used to generate the codes supported the themes; in other words, whether the themes found in step 3b were coherent and made sense with respect to the data set (i.e. the excerpts of dialogues used for the coding process in step 2b). For example, the temporary theme *animal variables discussed by*



*designers* became a subtheme of a more comprehensive final theme named *WCF dimensions informing the designers*. This included various other initial themes such as *considering interactors of cats*, *considering acceptability*, *considering perception*, etc., which were deemed to be subthemes, since they clearly corresponded to the WCF components such as the dimension *interactors*, and the principles of *cognitive acceptability* and *sensory imperceptibility* (see Figure 4.1 in chapter 4). Another example is the code *habituation of cat to device*. This was initially assigned to the subtheme *considering acceptability* since it expressed the idea that, if cats get used to the device, they eventually accept its presence on their bodies. However, by reading all the excerpts used for this code again, we realised that *habituation of cat to device* was actually inconsistent with the principle of *cognitive acceptability* and, therefore did not fit with the theme *WCF dimensions informing the designer*. Hence, we moved the code under another theme - *other than WCF influencing designers thinking* - and subtheme - *difficulty to align with animal perspective* - since it was likely a common prejudice that drove the thinking of P8 when *they* said: “*if you are designing a device that is designed to monitor the animals, it is really difficult to shape the technology on the animal. It has to be a device that is imposed to the animal*”.

The above revisions generated two final themes, each of which contained subthemes. Themes and subthemes are reported in Table 8.3 of the next section.

Fifthly and sixthly (steps 5b and 6b), the content and meaning of each final theme was explained (section 8.4) and discussed (section 8.5) as to whether the themes reflected the WCF and why.

#### **8.4 Analysis outcomes: Final themes**

At the beginning of each workshop, we administered and explained the WCF, asking the designers to use it for establishing wearability requirements. Hence, our goal in the analysis of their dialogues was to understand what elements of it they used, and what they got from it. Through the process described in section 8.3, we identified two themes related with the use and engagement that designers had with the WCF. These are:

- 1) *WCF dimensions informing the designers*. This theme was divided into seven subthemes: *discussions about deleteriousness*, *considering perception*, *considering acceptability*, *considering interactors of cats*, *animal variables discussed by designers*, *trading-off*, and *knowledge about the species*.
- 2) *Other than WCF influencing designers thinking*. This theme was divided into two subthemes: *human needs*, and *difficulty of aligning with animal perspective*.

Table 8.3 shows the themes and their subthemes.

Theme	Subtheme
WCF dimensions informing the designers	Discussions about deleteriousness
	Considering perception
	Considering acceptability
	Considering interactors of cats
	Animal variables discussed by designers
	Trading-off
	Knowledge about the species
Other than WCF influencing designers thinking	Human needs
	Difficulty of aligning with animal perspective

Table 8.3: Thematic table with themes, and subthemes identified during the thematic analysis.

Further, within each of these two themes, we also considered differences across the three teams (i.e. computer scientists (T1: P1, P2, P3, and P4), biologists (T2: P5, P6, P7, and P8), and cat carers (T3: P9, P10, P11, and P12)), to see whether there was any evidence that a different background might have led to different responses. These differences are highlighted and discussed below as they occur.

The next two sections (8.4.1 and 8.4.2) look through the two themes with the aim of elucidating their content and answering, in section 8.5, the two questions that drove the thematic analysis (i.e. *Did the designers engage with the WCF? Were the designers informed by the WCF?*) in order to understand the extent to which the designers' reasoning related to the WCF and, thus, to determine the framework's usefulness.

#### 8.4.1 Theme 1: WCF dimensions informing the designers

In order to accomplish their task of establishing wearability requirements and sketching mock-ups for a biotelemetry tag for cats, the workshop designers had discussions that related to various dimensions of the WCF. For example, they discussed the physical, sensory and behavioural characteristics of cats, and often referred to perception and acceptability aspects. We identified seven batches of codes that related to seven different components of the WCF and, therefore, we divided this theme into seven subthemes:

##### Subtheme 1 - Discussions about deleteriousness

In section 4.2, we referred to the moral obligation and scientific benefit of biotelemetry practitioners to employ tags that do not negatively affect the wearer.

Workshop participants conferred with each other several times about the necessity of not harming or impacting cats and about the need of considering their safety. Some of their comments were: “*could that put the cat in harm's way? (P10)*”, or “*actually, I was thinking: we were talking about the cat going to the wood, maybe getting caught. So, it is worth to think about a safe release (P6)*”, or “*yeah, if that is possible and it does not impact the cat (P2)*”, or “*if we go with collars, the collar can get stuck (P3). Yeah, we should think about [their] safety (P1)*”. Designers also discussed ways to minimise the burden of a tag on the

body, e.g. P3 proposed the solution of distributing the electronics on various areas of the body: *“what I am trying to do is to not put everything on the cat’s collar but rather to distribute around the body, so that he does not feel much weight”*; and, in every team, participants had the idea of transferring part of the technology from the body to the environment, to alleviate somehow a potential impact, e.g. P9: *“placing a radio station or a kind of station around the area where you know the cat goes, so you can download the positions of the cat without affecting the cat welfare. There’s nothing on the cat, or at least there is something on the cat, but it’s really lightweight”*.

These considerations include both the abstract concept of not harming a wearer, which should always apply regardless of context, and implementing means of achieving the WCF value and principles, the choice of which depends on the context. For example, non-deleteriousness was implemented by all teams through safety measures such as break-release mechanisms or stretchy material that avoid the strangulation of the wearer. Also, transferring the burden of a tag to fixed ambient stations was considered a possible way to achieve sensory imperceptibility, since lightening the weight on the animal’s body would result in a lower, and thus less perceivable, pressure.

Hence, we deemed that designers clearly met the value of ‘annulment of effect’ (comprising the biotelemetry postulations about non-deleteriousness and minimisation of effects), which is included in component b of the framework (Figure 4.1). Hence, we concluded that this was a WCF component that informed the thinking of designers during the workshops.

## **Subtheme 2 - Considering perception**

In section 4.2, we defined sensory imperceptibility as the quality of a device that should *“not be perceived by any of the wearer’s senses”*.

A continuously emerging topic, prevalent among the workshop participants, was the need to avoid interactors perceiving a device. Codes identified related to wearer’s smell and auditory perception; sensory capabilities of cats, their prey and predators; visual perception of the device by other individuals; the need for hiding a device and rendering it ‘invisible’; the need to minimise device-induced stimulation; and the concept that not wearing anything would solve many perceptibility (as well as other) problems. For example: P1 proposed that *“magnetic levitation is to have the bulky bit not attached to the cat”*; P8 suggested that *“the device has not to make any noise, including ultra and infrasound, no odour material has to be used”*; P2 argued that *“if there is a colour that prey recognise very easily, you do not want to put it on the cat [...], we need some camouflage fur”*; P5 declared *“I have been thinking how to make the device less visible”*; P7 reflected that *“their conspecifics would recognise it and they would discriminate the animal for that”*; P1 again said *“but there will not be frequencies there, right? We try to minimise that”*; and P9

proposed a solution by which *“there’s nothing on the cat, or at least there is something on the cat, but it’s really lightweight”*.

All the above discussions refer to a certain sensorial aspect (e.g. the fact that not having bulky bits attached to the body minimises touch stimulation) and we ascribed their occurrence to the principle of sensory imperceptibility contained in the component (b) of the WCF (Figure 4.1). Consequently, this is another WCF component that was considered by designers.

### **Subtheme 3 - Considering acceptability**

In section 4.2, we elucidated that *“cognitive acceptability is related to whether animals express the need to remove a tag they are wearing because they do not accept its presence”*.

During the workshops, designers discussed the tolerance of a cat to a device, e.g. P12: *“my cat, a couple of times had fleas, and I put a flea collar, and he stayed there with the back legs trying to push the collar away”*; the potential unacceptance of a device on the body, e.g. P8: *“if you put something to a place the cat cannot see or reach but they can feel it, as they are curious animals, I do not know how they could react, if they know there is something, but they cannot see or touch it. It may be drive them crazy”*; and things that cats do not like, e.g. P2: *“the cat won’t like anything rubbing or pulling or chafing”*, or P1: *“the fact is that cats do not really like anything on their bodies”*). Designers also considered comfortability as a way to increase the acceptance of a device on the body, e.g. P7: *“maybe, you can use that part of the animal to attach it firmly, not giving that much discomfort”*; and discussed how keeping the device always attached would reduce intrusiveness, e.g. P11: *“I mean, the idea of the fact that you don’t have to take the collar off to recharge it or to get the data off it, definitely reduces the intrusiveness of the device”*, or P7: *“I think it is worse for the animal to have it remove it and put it again and then remove it. If you can leave everything as it is, and then you are able to get what you need is better for the animals. If you detach the device, you are moving the equilibrium”*.

These codes demonstrate that the designers were concerned about the possibility that cats might not accept an object attached to their bodies (including the fact that detachment and reattachment would remind the animal of the object’s presence). This is in accordance with the principle of cognitive acceptability included in the component (b) of the framework (Figure 4.1). Hence, we deemed that the abovementioned designers’ discussions were informed by that element of the WCF.

### **Subtheme 4 - Considering the interactors of cats**

In section 4.2, we explicated that *“Interactors’ refers to wearers and individuals significantly interacting with them”* and that *“the principles and values for wearability do*

*not just relate to the wearers themselves, but they also apply to other individuals significantly interacting with them”.*

During their discussions, designers continuously referred to conspecifics, prey, predators, and other animals interacting with cats. For example, P2 reflected: *“what about cat leadership? If someone was the leader of the group and they saw something, one of the members all of a sudden notice the device. [...] I was just thinking about the fact that if there is an animal that gets groomed more, like an alpha-male or alpha-female...If an alpha male gets groomed more than any other animals... [this could be disruptive]”*. Likewise, P8 said: *“it is important that other animals do not investigate. The device has to be inconspicuous enough for prey and predators, so if [the cat] is hunting mice we do not want something that gives his position”*. Very explicitly, P5 asserted that *“[to me] significant others are the ones the cat could interact with, so other cats, dogs, and humans, people that are living with him”*. Participants in T3 also considered humans (and even cars) as potential harmful interactors. For example, P10 said: *“other people [can interact]. That can be a bad thing, some people can harm cats”*; and P11 stated: *“yes, there are nasty people with cats”*.

Clearly, component (c) of the WCF, namely the dimension related to interactors (Figure 4.1), raised awareness about the fact that the interaction between the wearer and other individuals should be considered when designing a wearer-centred device. Thus, designers also used this component of the WCF.

### **Subtheme 5 - Animal variables discussed by designer**

In section 4.2, we clarified that *“animal variables refers to characteristics of interactors, their activities, and environments, consistent with their biology and lifestyle”*.

Throughout the workshops, the designers considered locations and features of a device with respect to behavioural activities of cats, e.g. P1: *“I would not put anything on the fur because the cat will groom it”*; body parts’ movements, e.g. P3: *“it is possible to cover something from here, but the legs will lose the movement”*; interspecific communication, e.g. P8: *“it is not a good idea to put the device in body parts important for communication”*; personality, e.g. P3: *“...but it depends from cat to cat also, no? Like for aggressiveness, not every cat is aggressive...”*; habits, e.g. P12: *“but what if the cat roams free outside his house...”*; context, e.g. P8: *“cats can use cat flaps [and have to pass through it]”, or P2: “I think food is not a problem for this cat [because he is domestic]”*; hunting strategies, e.g. P2: *“...when [cats] try to not be seen, like stalking [a prey] is important for cats”*; living environments, e.g. P7: *“this cat is having an active life in the wood [nearby his house]”*; mating activities, e.g. P3: *“[cat females] do not attract the male with the body colour”*; physical characteristics, e.g. P2: *“It does not work on short-hair cats”*; physiology, e.g. P9: *“what if he is moulting? That’s a problem I guess, when there is the changing skin and*

fur”; sociality and interaction with other cats, e.g. P7: *“their conspecifics would recognise [the tag] and they would discriminate the animal for that”*.

This batch of codes shows that the designers considered various animal variables, putting the characteristics, activities, and environments of a wearer at the centre of the discussion. This is consistent with what the WCF prompts to do with its component (d), animal variables (Figure 4.1), that is: accounting for species-specific traits of interactors to establish requirements. This suggests that the framework informed designers’ discussions to account for species-specific aspects of an animal wearer’s experience (WX) and, therefore, we deemed that designers used this component of the WCF.

### **Subtheme 6 - Trading-off**

In section 4.2, we explained that *“design trade-offs’ refers to the importance of managing possible conflicting requirements”*; for example, when the current technological capabilities do not allow one to achieve a certain optimal wearability requirement.

Sporadically, designers mentioned technological capabilities that might constrain a wearer-centred design, e.g. P8: *“weight and stuff is going to depend on the kind of device and how the device operates”*; user priorities, e.g. P8: *“incising the cat’s skin to put inside just a GPS, I would not do it, but if it is for a [cat life-saving] pacemaker, yes”*; and they reasoned about the feasibility of implementing some of the requirements established, e.g. P2: *“but you need to think about the cable, they need to be long enough for when you stretch and pull the whole collar, so that they do not break”*; or P11: *“I don’t know if that is technologically possible”*.

These excerpts show that designers had some conversations about what constrains a design, what is (personally) appropriate, and what may be feasible. This matches with the component (g) of the framework (Figure 4.1) and supports the interpretation that the dimension related to trade-offs might have influenced the thinking of the designers.

### **Subtheme 7 - Knowledge about the species**

In section 4.2, we observed that *“it is fundamental for a biotelemetry designer to acquire biological information about the species of interest if a wearer-centred design is the goal”*.

Designers were made aware that they could consult a cat behaviourist for enquiries about the biology of the species. T1, which was composed of computer scientists with no knowledge about cats, made use of the expert ‘tool’. For example, P1 and P2 respectively asked questions such as *“which range of colour do [cats] see?”* and *“is there an area on the cat’s body that gets touched least from other cats?”*. However, both T2, which had a cat guardian among its members, and T3, which was the team of cat carers, analysed the biology and behaviour of cats on their own, sharing their personal knowledge and experience, and preferring to question each other, or a cat carer in their team, rather than the expert. For

example, P7 mentioned *“I don’t know if you have ever had a cat, but this is the only part he cannot reach when grooming”*; P11 shared their knowledge that *“electro sensing is an interesting [variable] because apparently, [cats] can hear the buzz of 240-volt electrics. They can detect that”*; and P8 questioned the cat carer in their team (T2) to ask: *“as you are a cat owner, how easy is to take stuff from the neck of the cat?”*.

Here we found the first relevant difference across teams. In fact, component (a) of the WCF (*knowing the species* (Figure 4.1)), was used in the form of asking an expert, but only by the members of T1, while the other teams considered the advice of cat-caring colleagues sufficient. However, although personal experience and knowledge can provide good information, this can be biased. This issue is well demonstrated by subtheme 2 of the next theme, under which participants’ (especially for cat carers’) difficulties of aligning with animal perspective are collected together. In conclusion, this component of the framework was only partially used by designers since not all the workshop teams considered the support of the expert useful.

#### **8.4.2 Theme 2: Other than WCF influencing designers thinking**

Among the designers’ discussions some topics not aligned with the WCF which emerged while analysing the dialogues. These were collated into two subthemes, and regard discussions about human needs and the difficulty of aligning designers’ thinking with the animal’s perspective:

##### **Subtheme 1 – Human needs**

Although the aim of the workshops was establishing wearability requirements, designers of T2 and T3 also discussed the needs of the (human) users, and in some cases, they considered such needs as primary with respect to animal wearer requirements. For example, P6 declared: *“I would incise the skin [to insert the device] if it is worth, if for example I am losing [my cat] very often and I want absolutely to know where it is, I may decide to go for it”*. When participants of T3 discussed the texture of the case, P10 thought about the user’s need to ensure that they would not lose the device as a consequence of a cat’s attempt to remove it: *“I was thinking to keep that smooth, because otherwise, when you’ve got cats who manage to pull it off...”*; P9: *“can they grasp it?”*; P10: *“yes, they might pull it from here”*. In particular, T3 (i.e. the cat carers) discussed functionality and data-gathering aspects. For example, although they initially focused on designing small electronics to be distributed around the collar to obtain a less chunky device, soon after their reasoning changed; when they realised that there was some extra-room in the mock-up they had designed, the team members imagined using the available space to augment the capabilities of the GPS with adds-on, basically eroding the optimal wearability they had reached. A discussion followed about what accessory widgets might be able to provide further data for users. P9 started saying: *“it will be interesting to add some more stuff now that we realised [that] we have more space”*; to which P12 answered: *“what about temperature sensors? It*

*could be a nice add-on to consider, because you can track the cat movement, but then you might correlate with behaviour outside and the temperature”. P9 even thought of things that would render the device more sellable: “commercially speaking, every cat and every owner of a cat has different needs [...] so in this way you can personalise the band and then you can change colours. You can play with all this kind of options to sell it”.*

In this subtheme we find the second difference across teams that might have come from their background. Although all three teams established wearability requirements by making use of the WCF (as shown by theme 1), T1, which was composed of computer scientists, seemed to be able to focus more on the task of establishing requirements for the wearer. On the other hand, T2 and (especially) T3, which were also potential or actual users of a biotelemetry technology, discussed also user requirements that in some cases weakened the wearability requirement debated only few minutes earlier. The wearer-focused performance of T1 might be due either to computer scientists’ familiarity with using design frameworks, or to their ongoing consultation of the cat expert (who could have indirectly reminded them of their primary task), or both. In contrast, T2 and T3 based part of their requirements analysis on their own knowledge of the species, which might be the reason why they diverted from their task: the personal experience of animal guardians can bring to the fore various human needs that range from protecting the cat to discovering more about their roaming habits, thus inducing designers to spend time thinking about user requirements and diverting their attention from the animal’s perspective that the WCF aims to elicit. Indeed, this subtheme shows that occasionally designers in T2 and T3 lost their focus from their primary task (establishing wearability requirements) and that this was a background-related issue. In part, this reinforces our thesis about the need for design instruments that can guide a systematic requirement analysis specific for a design goal, especially when designers are challenged to design technologies centred on other animals’ perspectives. However, it also shows a limitation of the current WCF version, which was not always able to drive designers’ thinking towards consistently recognising animal wearers as central stakeholders.

### **Subtheme 2 – difficulty of aligning with animal perspective**

The WCF has its foundations in the basic principle of Interaction Design that it is technology that should adapt to interactors. However, during the second workshop, biologists expressed the concept the other way around: that the cat has to get habituated and adapt to a device or that, since a device is currently in use, it must be appropriate. For example, P6 proposed keeping the collar constantly attached to the cat’s neck and have a battery hanging from the collar as a pendant, so that this would be easy to detach. When P7 argued “*but [the pendant] can be annoying*”, P6 defended *their* idea by saying “*why not, I have seen cats with ID tags*”. Along the same lines, P8 proposed “*a neck-based solution, because domestic cats, most of them, are already wearing collars, so they are already used to them*”. When



P8 was challenged (by another participant) that a current design does not necessarily mean that it affords wearability, *they* responded: “*but if you are designing a device that is designed to monitor the animals, it is really difficult to shape the technology on the animal. It has to be a device that is imposed to the animal*”.

Another difficulty in aligning with the animal perspective was shown during the workshop with cat carers, who in a couple of instances minimised a potential side effect induced by a device, bringing their personal experience as evidence. For example, P11 reported that their cat had worn a GPS in the past and commented about the size: “*I looked at [the device] and thought: that’s quite a significant weight. My cat, I thought, would hate it, but absolutely not bothered by it whatsoever. Most cats would not be bothered. Certainly, an eight-kilo male cat, I don’t think would be at all bothered with something that’s that size*”. This is in contrast with our empirical evidence from study 1 (chapter 5) which demonstrated, through systematic observations of cats during their daily activities, that animals can have adverse reactions towards a body-attached device. P11’s ability to observe *their* cat while wearing the device was limited in time and type of environment, since the animal was fitted with, and released from, the GPS a few minutes before leaving and after returning home. Hence, P11 did not have evidence to support *their* assertion and, from the enthusiastic tone of *their* voice, we suppose *they* were more likely focussing on satisfying *their* need to monitor the cat.

Overall, this subtheme shows two difficulties in aligning with the animal’s perspective from T2 and T3. The first one is evidenced by the discussion of the biologists, who thought about habituation as a way to accomplish wearability and referred to conventional devices as acceptable solely based on the fact that these are usually worn by cats. The second difficulty is evidenced by the discussion of the cat carers, who had the tendency to minimise the impact of certain potential effects, founding their considerations on personal experience as users of biotelemetry.

## **8.5 Discussion**

The thematic analysis method adopted to examine the workshop dialogues allowed us to understand whether designers were informed by the WCF during their requirements activities and to what extent. Having interpreted the dialogues at a semantic level, we deem that the seven components of the framework drove the designers’ thinking towards establishing the wearability requirements reported in section 6.1.4. From subthemes 1 to 6 of theme 1, designers of all three teams used a WCF dimension, by directly or indirectly referring to it. The most discussed items were the two design principles of sensory imperceptibility and cognitive acceptability, which were debated with the aim of rendering the device imperceptible and acceptable to both wearers and other individuals interacting with them. Clearly, designers gained the notion of significant others, since they regularly referred to conspecifics and other species interacting with the wearer throughout the whole

discussion. Hence, the interactors dimension repeatedly informed the requirements elicitation process during the workshop. Behavioural activities, physicality, intraspecific communication, physiology, personality, hunting and mating strategies, habits, and living context and environments were all animal variables considered for establishing wearability requirements by one or more teams. This shows that designers put the wearer at the centre of their requirements analysis both at a species-specific level (e.g. considering the impact of a device on cat-universal behaviours such as grooming) and contextual-individuality level (e.g. considering the problems that could arise from the roaming habits of a domestic individual). The value of annulment of effect was generally expressed by all teams in terms of not harming the cat, of minimising the effect of a tag, and of safeguarding the integrity of the wearer. These arguments definitely aligned with the specific aspects of the values defined by the WCF. Finally, though sporadically and with few details, the necessity of trading-off requirements was also debated, showing that this WCF component was useful to elicit reflection in this area.

No teams had a proper discussion about physical unobtrusiveness. Only T1 mentioned (once) the importance of not using a harness because “*the legs will lose the movement*” (P3), and during the T2 workshop it was said that “[the device] *has not to obstruct the hiding and running*” (P8). Although these two insights might have been influenced by the principle of physical unobtrusiveness, we did not consider them sufficient evidence to claim that the designers used this particular principle of the WCF, since they were only quickly touched upon. However, this does not exclude that, at an implicit level, designers might have considered that obstruction of movements is connected with perceiving and accepting impediments. Thus, through the achievement of imperceptible and acceptable devices, unobtrusiveness would have also been implicitly achieved.

Concerning the knowing-the-species component (subtheme 7 of theme 1), this was used only by the team of computer scientists (T1). This indicates a limitation in the use of this specific component of the WCF when biotelemetry users are involved in the designers’ teams, since it seems that the participants’ experience and needs as users were considered more than the knowledge and expertise of an animal expert. However, precisely because designers of any degree of expertise might have biases inherent to their own knowledge, or to the knowledge they think they have, arguably it is important that they systematically refer to this component to avoid such biases. Thus, the limited use of the knowing-the-species dimension highlights the need to find a way of enabling designers to make systematic use of it.

Overall, with six items used by the designers, one partially used (i.e. by only one team), and one not used (at least explicitly), we deem that the workshop participants engaged with and were informed by the WCF regardless of their background (with the only exception of subtheme 7 of theme 1).

However, the process of establishing the set of wearability requirements through the WCF presented some inconsistency with the framework. From the findings reported in theme 2, other factors influenced the designers' thinking and these are mainly ascribable to: 1) the nature of some designers as users (who put occasionally their needs above those of cat wearers), and 2) to the difficulty of fully projecting one's own mind into the perspective of an animal wearer (e.g. thinking that ID pendants do not annoy cats because they wear them and can get easily habituated to them - in spite of the fact that cats do not choose to wear them – or thinking that a potential side effect is not important - probably because it is not straightforward to interpret signs of discomfort from an animal). The findings also show that such influencing factors were not shared across all the three workshop teams; actually, only the biologists and cat carers discussed user needs, or habituation, or underestimated a potential impact.

Certainly, since design frameworks enable flexible and creative thinking, inexperienced designers such as those composing T2 and T3 might have suffered from the lack of specific instructions that could help to operationalise the WCF. As evidence for such a struggle, at the end of the T3 workshop, P12 commented that it would have been useful to have more precise directives: “[the WCF] *it's more of an anthology, like the whole landscape of all the variables and things to consider. The only thing is that, maybe, I think a kind of protocol could be like a companion to [the WCF], like a step-by-step guide*”. Indeed, the current version of the WCF could be complemented by an execution protocol allowing every designer, regardless of their background, to conduct a consistent systematic requirements analysis focused on the task. Such complementary protocol to the WCF might provide a specific guidance on how to go through the elements of the framework without incurring the limitations of the prescriptive approach typical of guidelines. Arguably, with a protocol at hand, the team who took cat knowledge for granted (i.e. T3) would have been required to consider the knowing-the-species dimension systematically.

However, although theme 2 shows this drawback, the thematic analysis shows that the WCF was quite an informative instrument for each team. In fact, the majority of the dialogues focused on wearers and each workshop produced mock-ups that had features consistent with the WCF dimensions. We report the case of P8 as evidence that, although theme 2 showed some limitations in the use of the WCF, this did not prevent the framework from usefully supporting the design process. This participant defended *their* proposal to design a neck-based solution by saying that cats are used to wearing collars and, therefore, they can get easily used to them. Then, P8 reinforced this concept by stating that, because it is difficult to shape a technology on the animal, a device has to be imposed on the animal. However, although *they* expressed these thoughts, when it came to present *their* idea of a wearer-centred device, P8 proposed the following wearability requirements: “*we know cats rub their head, groom their head, they can use cat flap, so the device has to be a reasonable size to pass through. It is important that other animals do not investigate. The device has*

*to be inconspicuous enough for prey and predators, so if he is hunting mice, we do not want something that gives his position. Cats run and hide so [the device] has not to obstruct the hiding and running. The device has not to make any noise, including ultra and infrasound, no odour material has to be used, it is not a good idea to put the device in places important for communication. The sensitiveness of the skin has to be considered, the device must not have taste. This is what I caught [from the WCF]".* This shows that, although P8 had some preconceptions, this did not prevent *them* from accomplishing the task of establishing requirements consistent with the cats' characteristics, activities, and environments.

## **8.6 Chapter summary**

This chapter has analysed the discussions that the three teams of designers had during the workshops with the aim of investigating the designers' use of the WCF and, therefore, evaluating its usefulness. Through a thematic analysis of the designers' dialogues, two themes were found, which reflected what elements of the framework and what other than the framework informed the designers. The outcomes support the conclusion that the WCF is a useful tool for informing wearability, since its elements elicited many discussions that put the animal stakeholders at the centre of the workshops' design process. However, some limitations have also become apparent, which will need to be addressed in subsequent iterations of the framework. This issue will be touched upon again in the next chapter when future work is discussed. Chapter 9 also triangulates all the outcomes of the three studies (workshops, study 1, and study 2) and discusses the contributions of this thesis.

## 9. CONCLUSIONS

The biotelemetry literature reviewed in chapter 2 showed that physical aspects of a device can significantly contribute to impact both the animals who carry the tags on their bodies as well as the quality of the data. The need for reducing device-induced negative effects, and the lack of a structured approach to accomplish a less-impinging design, drove this work to investigate the thesis by which designing for good wearability would improve the bodily interaction that animal wearers have with tags, thus reducing the impacts of tagging and improving data reliability.

A main question was set to inform the research: *How can wearability in animal biotelemetry technologies be systematically designed for to improve the wearer's experience and therefore reduce the impacts that the technology has on them?*

The answer was found in the theoretical discourse of Blackwell and Green (2003) for whom design frameworks foster innovative thinking in a systematic and creative fashion. Hence, the aims of this research were 1) developing a design tool, called the Wearer-Centred Framework (WCF), to help designers to systematically achieve optimal wearability, and 2) evaluating whether the WCF was a useful tool to inform the process of designing for good wearability. Such aims were guided by three operative questions:

- 1) What elements might constitute such a wearer-centred framework?
- 2) How could the framework be applied during the design process?
- 3) How could the usefulness of the framework as a design-informing tool for wearability be evaluated?

Answering the first question involved gathering information from the literature to develop the WCF (chapter 4). The second question was addressed through a series of workshops during which the WCF was applied by participants to conduct a requirements analysis with animals (cats) as the primary stakeholder of a biotelemetry device (chapter 6). Addressing the third question entailed first conducting an observational study (study 1) to investigate animal (cat) wearers' experience (WX) of wearing different tracking devices (chapter 5); then designing a prototype derived from the requirements established during the workshops (chapter 7); and finally conducting a second empirical study with the prototype (study 2) to evaluate its wearability (chapter 7). Through the studies and the prototyping stage, the third question was addressed by comparing the requirements that the designers identified through the application of the framework with requirements empirically derived (chapter 6), and by investigating the cats' WX with the prototype (chapter 7). In parallel, the question was also addressed analysing the use that designers made of the WCF during the workshops (chapter 8).

This chapter firstly discusses the outcomes of the workshops and of the two empirical studies to understand the extent to which the WCF informed a wearer-centred design process (section 9.1). Secondly, the chapter articulates this thesis' contributions to knowledge within the fields of animal biotelemetry, Animal-Computer Interaction (ACI), animal behaviour, and wearable design (section 9.2). Thirdly, the chapter presents a reflection on the limitations of the WCF and of the approach undertaken to develop and evaluate it (section 9.3). Fourthly, future iterations of the WCF and its possible future applications within ACI are suggested (section 9.4).

## **9.1 Validity of the WCF**

Study 1 served as a baseline to understand cats' experience (in terms of discomfort) of wearing off-the-shelf devices, against which to compare their experience of wearing a prototype designed by following the wearability design principles, values and dimensions featured by the WCF, in order to verify whether there had been any improvements. The cats' experience was investigated by observing and measuring stress-related behaviours and incidents of direct interactions with the tags. Findings included the identification of three behavioural indicators of discomfort (i.e. single licking strokes of the fur around the neck, scratching, and head/body shaking, see section 5.5.3), and nine wearability requirements (see Table 5.12). These two kinds of data were used to evaluate the usefulness of the WCF as follows:

The indicators were measured again during a wearability test of the prototype (study 2). It was found that such behaviours either diminished in frequency or intensity with respect to the findings of study 1. This suggested that the prototype, whose design was informed by the WCF, provided a better WX for cats than the off-the-shelf devices tested in study 1. If the wearer-centred prototype informed by the WCF was less uncomfortable than off-the-shelf devices, this arguably means that the framework was useful to achieve good wearability (at least to some degree).

The nine requirements derived through empirical observations in study 1 were compared with the twenty-two requirements established heuristically by designers through the application of the WCF during the workshops. The comparison showed that it was possible to obtain a wider variety of requirements for a larger array of animal variables with a heuristic approach (informed by the WCF) than with an observational approach, and that several of the workshop requirements were equivalent to, and in some cases more detailed than, the study-1 requirements, thus validating the significance of the workshop requirements. This provides evidence that the WCF is an effective instrument that enables designers to establish wearability requirements through a heuristic approach, which is less intrusive compared to an empirical approach whereby animals are fitted with devices (thus causing an impact on them) and requirements are elicited observationally.

Furtherly, the usefulness of the WCF as an informing instrument for designers was also assessed by thematically analysing the workshop dialogues. The systematic analysis of designers' dialogues shows that the tool was directly and indirectly used during the workshops, helping the designers strive for good (feline) wearability and fostering their innovative thinking. Designers were able to discuss design variables and craft mock-ups consistent with cat stakeholders' characteristics, activities and environments having at their disposal nothing but the WCF, a stuffed cat, some prototyping material, and their personal knowledge. In this regard, the thematic analysis suggests that the informing power of the former (i.e. the WCF) was greater than the influence of their personal knowledge (i.e. designers' sensitivity). Although some of the designers' reasoning appeared to be inconsistent with the values, principles and dimensions of the WCF, the themes and subthemes emerging from the majority of their dialogues show that most of the designers' thinking was indeed aligned with the values, principles and dimensions of the WCF. Hence, this was further evidence of the significance of the WCF as an informing instrument when designing for wearability.

In conclusion, although the version of the WCF developed and evaluated in this dissertation has some limitations, research findings show that it is a useful and informative tool when designing for wearability – particularly in the case of cat biotelemetry. Overall, the WCF enabled designers to establish requirements heuristically that were validated through the design and wearability test of a prototype, and through the comparison with requirements established empirically. The evidence from the evaluations supports this dissertation's thesis that wearability in animal biotelemetry can be systematically designed by means of the WCF that was developed. Ultimately, the WCF could be employed as an instrument to inform design practice when the aim is placing animal wearers at the centre of the design process.

## **9.2 Contributions to knowledge**

This dissertation has presented the development of a design framework, an application of the framework within three workshops, design prototyping informed by the outcomes of the workshops, and two observational studies with animal participants, in order to demonstrate that designing for good wearability can improve animals' wearer experience with biotelemetry devices and that such an improvement is achievable by means of a systematic heuristic approach. Having developed and applied the framework, and then evaluated its usefulness with both human participants (by analysing the dialogues of the workshop designers) and animal participants (by observing and putting in relation cats' reactions to off-the-shelf devices and to a framework-derived prototype), this thesis has demonstrated that adopting wearability as a fundamental design goal has the potential of reducing negative effects on WX when designing wearable technology intended for animals. To this end, this thesis has brought together perspectives and concerns from the

fields of Animal Biotelemetry (which presents the problem of designing better devices on welfare and scientific grounds), Interaction Design applied to wearable computing (which provides theoretical instruments such as UCD for achieving better design), Animal Behaviour and Welfare (which provides methodological and ethical frameworks for interpreting animals' experience) and Animal-Computer Interaction (which recognises animals as primary stakeholders in the design of technology intended for them).

At the crossroad of these different fields, the research presented in this thesis makes theoretical, methodological, design, and animal welfare contributions to knowledge that are relevant to ACI.

### ***Theoretical contribution: The Wearer-Centred Framework***

This research delivers the first comprehensive wearer-centred design framework for animal biotelemetry and animal wearables more broadly. Informed by, and extending, the fundamental tenets of User-Centred Design, the WCF proposes essential values, principles, and goals of wearer-centred design, providing a conceptual roadmap for designers. By helping designers to systematically focus on animal wearer stakeholders, to apply design principles for reducing any impacts from wearables, and to design for wearability, the WCF can facilitate wearer-centred design when the wearers are not users and, therefore, designing for usability and user experience is not sufficient to deliver a good product. Thanks to the level of abstraction of its elements and the modular organisation of the process it represents, the framework is a flexible tool enabling the elicitation of a wide range of requirements. This suggests its potential for adaptation to diverse design contexts and wearer species (whether non-human or human animals), fundamentally improving on more rigid design guideline-based approaches currently used in biotelemetry design.

### ***Methodological contribution: Heuristic and empirical approaches***

This dissertation demonstrates a heuristic application of the framework in a collaborative setting through a series of workshops during which teams of designers were able to use the framework to identify a set of requirements that informed a wearer-centred prototype, whose wearability was superior to that of commercial counterparts. Such a *heuristic approach* to gathering *requirements* enables designers to undertake an iterative wearer-centred design process consistent with UCD values but without the need to involve animal wearers when this could impact their welfare, until a suitable design can be achieved.

However, there are moments in the design process when, in order to understand and design for wearer experience, wearers do need to be involved in the evaluation of products or prototypes. Thus, this research proposes an *empirical approach* to the *evaluation* of wearable biotelemetry, based on the transfer and adaptation of ethological observation protocols designed to rigorously record and interpret animal behaviour. The proposed empirical protocol integrates the use of quantitative and qualitative observations, according



to specific criteria and temporal patterns, to understand animals' responses to technological interventions. The protocol could be applied to a range of ACI other research projects where, consistent with ACI and UCD values, understanding animals' experience with technology is key. Here it is specifically applied to the investigation of cats' reactions to biotelemetry devices, leading to the identification of species-specific behavioural indicators of responses to wearable devices as well as species-specific wearability requirements.

### ***Design contribution: Wearability requirements***

This research delivers the first wearability requirements, heuristically and empirically derived, that could be used as a starting point of an iterative design process aimed at producing cat-centred wearable devices, and that provide a base for designers to design for and further investigate cat wearability. Here, the proposed set of requirements is interpreted in a first biotelemetry prototype for cats, which has been designed through a systematic wearer-centred approach and which could be further developed through an iterative design process to develop the first commercial, genuinely cat-centred tracking device.

### ***Animal welfare contribution: Evidence of impacts***

This research provides empirical evidence of specific behavioural device-induced effects on domestic cats from tracking devices commonly marketed as cat-friendly. Such information show that seemingly least-obtrusive devices affect wearers at a temporary and less overt level of discomfort than physical harm (i.e. skin abrasion). On the one hand, this contributes to the knowledge of the problem of impacts with detailed information specific for cats, which show that they can be affected even when it seems they are not. On the other hand, it corroborates the claim underpinning this thesis that it is important to improve the design of biotelemetry tags in order not to affect animals at any level of deleteriousness and in order to achieve satisfactory animal welfare. In turn, such awareness fosters further investigation on device-induced impacts from ACI researchers, proposing wearer-centred design as an approach that helps ACI to achieve its aim of improving animals' lives by fulfilling their needs.

In addition to the above contributions to knowledge, this dissertation presents a comprehensive review of previously dispersed and fragmented multi-disciplinary sources discussing applications, problems, and solutions in biotelemetry design (see section 2.3.2), thus providing a 'one-stop shop' for biotelemetrists and designers who wish to understand design practises in wearable design.

### 9.3 Limitations

The framework presented in chapter 4 is intended as a tool to be used by designers to focus on animal wearers as primary stakeholders of a biotelemetry technology, enabling concurrently systematic and creative thinking that aims to achieve the goal of designing for wearability. Unlike less flexible instruments, such as prescriptive guidelines and checklists for designers (Blackwell & Green 2003), the WCF enabled research participants to formulate innovative ideas and to consider many of the animal variables at stake. However, such flexibility of the WCF is both its strength and its limitation. Considering many variables at once might be to the disadvantage of the focus on animal stakeholders. In the workshops, the inexperienced designers of teams 2 and 3 demonstrated this by getting repeatedly distracted discussing some (human) user's need. Hence, further research with designers might be needed to understand how the framework might be enhanced or complemented to help them keep the focus. This is proposed as future work.

Although the WCF is intended to be potentially and flexibly applied to establish wearability requirements for any animal species, another of its limitations is that it is dependable from what is actually known about a species and about individuals. This highlights the need for designers to acquire the required knowledge and the difficulty of developing a design when the species' behaviour is not well understood by the scientific community in the first place. However, the WCF can be used even when minimum information about a species and individuals is available (e.g. morphology or living context), allowing the elicitation of requirements related to such information, at least. In such cases, differences between individuals of a same species can be accounted for when reflecting on their physical characteristics and environmental contexts, as indicated by the component d (i.e. Animal Variables) of the WCF.

By the same token, it cannot be excluded that some of the findings related to the WCF usefulness might have been influenced by the fact that many people are familiar with domestic cats to different degrees. Hence, they may be partially dependent on the choice of the model species. However, the fact that even participants who were less familiar with cats could still make fruitful use of the framework suggests that this heuristic approach is promising. Future iterations and evaluations, through its application with other species, will arguably strengthen the WCF as a heuristic tool.

Additionally, the study-1 requirements should not be taken as exhaustive, since they come from the first study of its kind, which will benefit from further investigation and replication to confirm and extend the requirements. Similarly, findings from study 2 are indicative and require further investigation encompassing experimental conditions within the same study. One limitation concerns the selection of participants. In a quantitative ethological study that employs statistics, it is fundamental to select these randomly; that is, selecting them

from a pool of individuals that have the same possibility of being chosen (Martin and Bateson 1993, pp. 131-132). However, cat participants for study 1 and 2 came from a population of cat carers interested in biotelemetry applications and responding to an advertisement. This was a *haphazard sample*: that is, “*one where the sample is chosen according to an arbitrary criterion such as availability*” (Martin and Bateson 1993, p. 132). Hence, the three indicators found in study 1 should be considered only for the participants of the wearability tests, and further ethological studies with proper random samples should be conducted in order to generalise the results that study 1 brought to light. Also, statistical tests encompassing cats’ demographics such as age, gender and weight were not conducted. This was because study 1 focused on exploring the extent of discomfort per se rather than investigating whether a sign of discomfort was age, gender or weight-dependent. However, such tests could be conducted in future wearability studies to investigate potential correlations with such factors and, therefore, acquire more precise measures of wearability.

With regards to the off-the-shelf devices and the prototype (which was built with actual electronics such as a GPS unit and batteries wired together to simulate the weight and other physical aspects of a wearable), none of the tags were in operation. This excluded the possibility of investigating impacts that could derive from frequencies emitted by functional devices (e.g. flashing lights, vibrations, electric sounds). Hence the spectrum of a cat’s WX investigated in this work is not comprehensive. Also, the actual prototype described in section 7.1.2 presented flaws which probably decreased its overall wearability (e.g. it featured an elongated case which could not be avoided due to the difficulty of crafting a complex stretchy design). Thus, further iteration employing more sophisticated materials will be necessary in order to better understand the extent of improvement reachable by means of the WCF.

However, the purpose of the prototyping was to demonstrate the application and usefulness of the WCF. While not having reached an optimal device or identified all the wearability issues limited the extent to which any improvements can be observed, the exercise also served to identify design and implementation flaws that should be addressed in future prototype iterations.

#### **9.4 Future work**

Frameworks are tools that progressively improve with the acquisition of new knowledge, and wearability is a very young concept in wearable computing and ACI, and a new concept in Animal Biotelemetry, which requires further analytical and empirical investigation. This research proposes a preliminary design framework which will need refinement, and probably will undergo changes, adjustments, and integrations in its content and structure due to the advancement of the research related to the concept of wearability. In this regard, future work in this area could continue to acquire, both analytically through a systematic

literature review and empirically through wearability studies, further knowledge about wearability and to integrate it into the framework's components.

To address the abovementioned challenge for non-expert designers to focus on the WCF's goal of designing for optimal wearability for animals, future work could investigate why this may have occurred (e.g. if it resulted from a flaw in the WCF or from a lack of understanding of animal behaviour and welfare issues) and how this problem might be addressed (e.g. by adding specific components to the framework). This would render the WCF more robust. One way forward could be to explore what teams of designers would do in different scenarios (when they are provided with the WCF and when they are not provided with the WCF) in order to investigate how their ability to focus on wearability requirements varies with or without the framework.

Although this research investigated and demonstrated the usefulness of the WCF with the domesticated species *Felis catus* as a model, future work could explore whether equivalent results can be obtained with other species of different categories such as wild species, and taxonomy classes and phylum<sup>37</sup> such as birds, fish, and invertebrates. This would confirm whether the WCF is a universal heuristic approach to designing for wearability.

Finally, the WCF (in its current version or in its refined versions) could be applied to the process of designing real biotelemetry devices involving actual developers and manufactures, in order to obtain a finished wearer-centred product that could be compared with off-the-shelf devices that were designed without following a wearer-centred approach.

## **9.5 Final remarks**

This thesis addresses the research goal of designing for wearability in animal biotelemetry by proposing a wearer-centred design framework that provides for the lack of a systematic approach to designing animal wearables, which is currently based on fragmented guidelines. The WCF was developed drawing key information from the literature and then applied to elicit heuristically derived wearability requirements during workshops. The design process conducted produced a prototype that implemented the requirements elicited through the application of the framework and that was tested with cat participants to evaluate whether good wearability was achieved (study 2). An experimental study (study 1) investigating cats' reactions to off-the-shelf devices provided empirical evidence that was triangulated with the outcomes from the workshops and the prototype testing to support the usefulness of the WCF as a design tool. In parallel, the WCF was evaluated with human designers by analysing the extent to which they made use of it. On a theoretical level, the WCF is proposed as a conceptual roadmap for designers that supports, and extends, UCD; on a methodological level, it is a practical tool that can inform a systematic approach to

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<sup>37</sup> Phylum and classes are biological categories used by zoologists to classify each species within the classification system called taxonomy.

designing biotelemetry wearables centred on animals' needs. Limitations of the framework are acknowledged, regarding its efficacy in keeping the designer's focus on animal stakeholders and the need for knowledge about an animal species' characteristics, activities, and environments in order to provide designers with relevant information to be used in the WCF. However, research findings show that the WCF informed the design of a wearer-centred prototype that outperformed off-the-shelf devices with respect to wearability aspects. Hence, the WCF can be considered a useful systematic heuristic approach and instrument for designing biotelemetry devices that afford good wearability for animals. Further iterations of the framework are envisaged as future work, including analytical reviews that might add new dimensions or integrate the ones already presented in the framework. This doctoral work also paves the road to WCF applications with species other than cats and wearability studies of wearer-centred prototypes derived from such applications.

The use of biotelemetry technologies on animals is growing, as well as the awareness that animals have the right of living their life unharmed when fitted with devices. This research acknowledges both advantages (e.g. monitoring pets' safety) and disadvantages (e.g. impacts on wearers) of using body-attached devices, in order to show the need for low-impinging monitoring. The WCF is a tool that can enable researchers and practitioners to design for wearability and, therefore, improve the physical experience that animals have with a device. Both the theoretical argument underlying this research and the application of the WCF for enabling a wearer-centred design are relevant for various categories of biotelemetry stakeholders: the monitored animals, who could benefit from an improvement of their welfare; biotelemetrists, who could rely on better devices for acquiring their data; welfarists, who could obtain empirical evidence supporting their call of considering animals' needs and characteristics; and biotelemetry designers, who could work with a tool enabling them to design wearer-centred devices which, in turn, would result in improved animal welfare and satisfaction of human users.

In conclusion, the use of biotelemetry technologies should never be detrimental to wearers. A negative wearer experience can be avoided by adapting body-attached devices to wearers. This thesis provides an approach to making this possible, shaping the future of biotelemetry design towards low-impact and reliable devices.

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## Appendices

### Appendix 1 – Ethics approvals and participant agreements

#### Human Research Ethics Committee (HREC)

From Duncan Banks, Deputy Chair  
The Open University Human Research Ethics Committee  
Email [duncan.banks@open.ac.uk](mailto:duncan.banks@open.ac.uk)  
Extension (6) 59198



To Patrizia Paci, Department of Computing and Communications, MCT  
Project title Monitoring Cat Activities for wearer-centred biotelemetry  
HREC ref HREC/2016/2202/Paci/1  
AMS ref N/A

#### Memorandum

Date application submitted: 02/02/16  
Date of HREC response: 24/02/16

This memorandum is to confirm that the research protocol for the above-named research project, as submitted to the OU HREC for ethics review, has been given a favourable opinion by Chair's action.

Please note the following:

1. You are responsible for notifying the HREC immediately of any information received by you, or of which you become aware which would cast doubt on, or alter, any information contained in the original application, or a later amendment which would raise questions about the safety and/or continued conduct of the research.
2. It is essential that any proposed amendments to the research are sent to the HREC for review, so they can be recorded and a favourable opinion given prior to any changes being implemented (except only in cases of emergency when the welfare of the participant or researcher is or may be effected).
3. You are authorised to present this memorandum to outside bodies such as NHS Research Ethics Committees in support of any application for future research clearance. Also, where there is an external ethics review, a copy of the application and outcome should be sent to the HREC.
4. OU research ethics review procedures are fully compliant with the majority of grant awarding bodies and where they exist, their frameworks for research ethics.
5. At the conclusion of your project, by the date you have stated in your application, you are required to provide the Committee with a final report to reflect how the project has progressed, and importantly whether any ethics issues arose and how they were dealt with. A copy of the final report template can be found on the research ethics website - [http://www.open.ac.uk/research/ethics/human-research/human-research-ethics-full-review-process-and-proforma#final\\_report](http://www.open.ac.uk/research/ethics/human-research/human-research-ethics-full-review-process-and-proforma#final_report)

Best regards,

Dr Duncan Banks, Deputy Chair

The Open University Human Research Ethics Committee

<http://www.open.ac.uk/research/ethics/>

**Animal Welfare and Ethics Review Body (AWERB)**



From Dr Duncan Banks, The Open University AWERB  
Email [duncan.banks@open.ac.uk](mailto:duncan.banks@open.ac.uk)  
Extension 659198

To Patrizia Paci, Department of Computing and Communications, MCT  
Project title Monitoring Cat Activities for wearer-centred biotelemetry  
AWERB ref AWERB/2016/2202/Paci/1  
AMS ref N/A

**Memorandum**

Date application submitted: 02/02/16  
Date of AWERB response: 24/02/16

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This memorandum is to confirm that the research protocol for the above-named research project, as submitted to AWERB for ethics review, has been given a favourable opinion by Chair's action.

Please note the following:

1. You are responsible for notifying AWERB immediately of any information received by you, or of which you become aware which would cast doubt on, or alter, any information contained in the original application, or a later amendment which would raise questions about the safety and/or continued conduct of the research.
2. It is essential that any proposed amendments to the research are sent to the AWERB for review, so they can be recorded and a favourable opinion given prior to any changes being implemented.
3. You are authorised to present this memorandum to outside bodies in support of any application for future research clearance. The ACI research protocol has already been given a favourable opinion by AWERB.
4. OU research ethics review procedures are fully compliant with the European Directive 2010/63/EU.
5. At the conclusion of your project, by the date you have stated in your application, you are required to provide the Committee with a final report to reflect how the project has progressed, and importantly whether any ethics issues arose and how they were dealt with.

Best regards,

Dr Duncan Banks, Deputy Chair

The Open University AWERB

<http://www.open.ac.uk/research/ethics/>



## Monitoring cat activities Information Form v 2.0 (7 Feb 2017)

Thank you for expressing an interest in this research project, which is part of a wider research programme on Animal-Computer Interaction currently being developed at The Open University's Centre for Research in Computing (<http://crc.open.ac.uk/Themes/ACI>).

I am a Research Student in Animal-Computer Interaction at the OU's Computing and Communications Department. In this research I am investigating the design of animal wearables such as activity monitors and GPS trackers specifically intended for cats. My aim is to uncover any limitations from the perspective of the wearer and identify design requirements for improving the wearability of such devices.

The objectives of this research are as follows:

- 1) gaining an in-depth understanding of the current design of off-the-shelf products in order to identify design limitations and, consequently requirements;
- 2) observing how your cat/s respond to the use of different devices and methods of attachment of the device;
- 3) evaluating with you and your cat/s design aspects that could improve the wearer experience for your cat; the outcomes of this study will inform the development of improved prototypes;
- 4) identifying design principles and research methodologies which are most appropriate for developing this kind of wearable device from a feline-centred perspective.

In order to achieve these objectives, at different stages, I would like to observe and, with your permission, video record daily activities of your cat/s and audio-record related discussions with you. I would also like for you and your cat/s to trial a variety of off-the-shelf devices as you deem appropriate for the welfare of the cat/s and for your working practices.

At all times I will interact with your cat/s under your supervision, unless otherwise specified by you. Should you at any time raise any concerns, I will immediately withdraw. At any time you can decline to answer any questions or terminate any discussion. At any time you can withdraw yourself and/or your cat/s from the study without justification.

No personal data relating to humans will be recorded in this research. Any video recordings of observational sessions and interviews with you strictly regarding the cat/s daily activities will be taken only with your explicit permission. In any case, any recorded data will be anonymised and securely stored; it will be accessed only by the researchers involved in the research and it will be protected by confidentiality according to The Open University's highest privacy protection standards.

Before any research findings are published, I will share them with you to give you the opportunity to express any concerns you might have and to ensure that these are addressed to your satisfaction prior to publication. Findings will always be published in anonymous form, unless you request otherwise (e.g. if you agree to co-author related publications). Photo, video or audio recordings will only be published with your explicit permission.

This research is conducted with the approval of The Open University's Animal Welfare Ethical Review Body and will fully comply with the Animal-Computer Interaction (ACI) Research Ethics Protocol provided to you together with this consent form.

If you are satisfied with the information provided here, and if you are happy to participate in this research and, as their legal guardian, are happy for your cat/s to participate with you, please complete the provided form.

Patrizia Paci, MSc  
Animal-Computer-Interaction Lab, Department of Computing and Communications  
The Open University, Walton Hall, Milton Keynes, MK7 6AA  
Email: [patrizia.paci@open.ac.uk](mailto:patrizia.paci@open.ac.uk)  
Tel: 07871 945 965





## Monitoring Cat Activities: Consent Form

I have read and understood the information regarding the project entitled Monitoring cat activities version 2.0 (7 Feb 2017). ☐

I agree to take part in the research together with my cat/s and consent to the researchers visiting my home and surrounding areas when I am at home and upon prior agreement, for the purposes of the project. ☐

I agree to the cat/s under my responsibility to be instrumented with a variety of off-the-shelf wearable devices such as activity monitors and trackers, with my approval. ☐

I give permission to the researchers to video recording my cat/s daily activities, and audio-recording related discussions with me. I am aware that any video recordings of observation sessions of cat behaviour and interviews with me will strictly regard my cat/s daily activities, and no human activities, whether of myself or of my human family members, will be registered. ☐

I am aware that I can decline to answer any questions or terminate any discussion, and withdraw myself and/or my cat/s from the study without justification at any time. ☐

By ticking the above boxes and signing this form I provide my consent on my behalf and on behalf of the cats named below, as their legal guardian.

Name of HUMAN participant	Names of FELINE participants	Signatures

Date:



## Workshop: designing a wearable for cats Information Form

Thank you for volunteering for this research project as a designer of a wearable device for cats. This work is part of a wider research programme on Animal-Computer Interaction currently being developed at The Open University's Centre for Research in Computing (<http://crc.open.ac.uk/Themes/ACI>).

I am a Research Student in Animal-Computer Interaction at the OU's Computing and Communications Department and I am investigating the design of animal wearables, such as activity monitors and GPS trackers specifically intended for cats. My aim is to uncover any limitations of existing devices from the perspective of the wearer and identify design requirements for improving their wearability.

The objective of the workshop is to understand how you apply a wearer-centred framework I developed in a previous phase of this research. The framework is intended as a guide for you to design a wearable for cats.

The outcomes of this workshop will establish wearability requirements and inform the development of improved prototypes. In order to achieve this, I would like to observe you during the workshop and, with your permission, video and audio record the discussion that you will have with other participants.

At any time, you can decline to answer any questions or terminate any discussion. At any time, you can withdraw yourself from the workshop without justification.

No personal data relating to you will be recorded in this research. Any video recordings of the workshop and any dialogue between you and the other participants will be taken only with your explicit permission. In any case, any recorded data will be anonymised and securely stored; it will be accessed only by the researchers involved in the research and it will be protected by confidentiality according to The Open University's highest privacy protection standards.

Before any research findings are published, upon request, I will share them with you to give you the opportunity to express any concerns you might have and to ensure that these are addressed to your satisfaction prior to publication. Findings will always be published in anonymous form unless you request otherwise (e.g. if you agree to co-author related publications). Photo, video or audio recordings will only be published with your explicit permission.

If you are satisfied with the information provided here, and you want to participate in this research, please check the following statements and sign the form.

Patrizia Paci, MSc  
Email: [patrizia.paci@open.ac.uk](mailto:patrizia.paci@open.ac.uk)  
Tel: 07871 945 965

I understand that my participation in this research is voluntary; I give permission to the researchers to video and audio recording the workshop session and the related discussions between me and the other workshop participants; I am aware that any video and audio recordings of the workshop will be kept confidential and securely stored, and analysed as data and used accordingly; I am aware that I can decline to answer any questions or terminate any discussion, and withdraw myself from the study without justification at any time.

By signing this form, I agree to participate in the workshop and I provide my consent to the researcher to use the data that will be generated during the workshop.

Signature:

date:

## Appendix 2 – List 1 of biological variables and List 2 of features of design

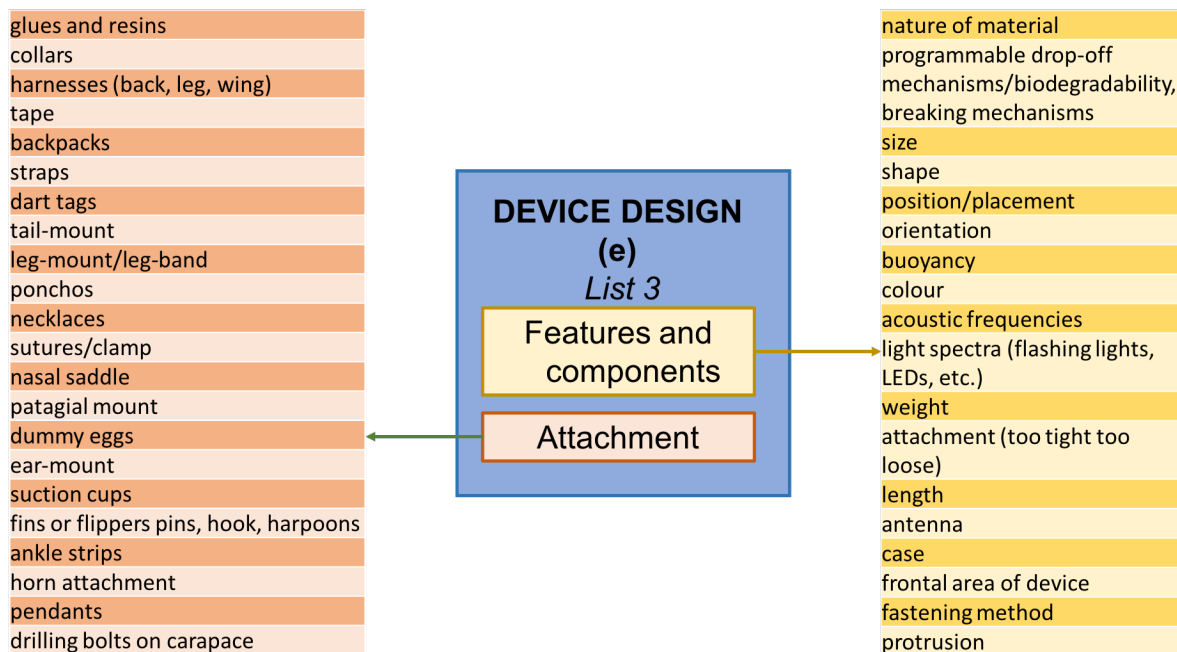
### List 1 of biological variables

VARIABLES	BIOLOGICAL ASPECTS
Sensoriality	
Touch	Perception is conventionally classified in five sensory faculties: touch, sight, hearing, smell, and taste. Indeed, in the animal kingdom sensoriality is more variegated and complex than this. To begin with, other species can have sensory capabilities not owned by humans (e.g., ability to sense the body heath of prey by means of infrared radiation receptors in rattlesnakes, or electro-frequencies used for communication and object location, or prey dizziness in electric fish), or sensory organs no longer functional in humans anymore (e.g., vomeronasal organ for pheromone perception in mammals). All animals included humans have internal sensory mechanisms they are not aware of (e.g., proprioceptors which reveal the muscles position and movement). Depending on the species, senses can have different magnitude (e.g., highly sensitiveness of dogs’ nose compared with the human one), or range (e.g., ability to hear ultrasound and see different colours in many mammals, or perceive wider light spectrum like UV in bees). Moreover, sensory tissues can be localised in different body areas than humans (e.g., ears for hearing in mammals, but legs in insects). In order to be as imperceptible and unobtrusive as possible, the instrumentation attached on the wearer’s body should be designed considering the relevant sensory capabilities and the position of sensory organs of the animal with respect to mechanoreception (which encompasses touch, hearing, equilibrium and postures), Photoreception (sight), Chemoreception (smell and plehming; taste is not relevant for biotelemetry design), thermoreception, and electroreception.
Hearing	
Equilibrium and postures	
Sight	
Smell and pheromones	
Heath sensing	
Electrosensing	
Physiology	
Energetics	Especially in wildlife where humans do not intervene in the administration of food, the equilibrium between incoming and consumed calories determines the success of an individual. Wild animals spend large part of their energy searching for nourishment which should be quantitatively and qualitatively adequate to their level of activity, stage of growth and life cycle in order to mature, maintain, be reproductive and survive. Energy expenditure, in concomitance with other vital physiological processes such as cyclic phases (e.g., periods in which food is scanty), body temperature regulation (e.g., through perspiration, insulation, or expositive behaviour), and life stages of an animal (e.g., growth, reproductive season, pregnancy, breeding, etc.) should be reflected before attaching a device.
Insulation and thermoregulation	
Cyclic phases	
Growth	
Gestation and parental investment	
Morphology	
Body shape	

Body weight	Body morphologies are the visible evidence of animal adaptation to the environment; through them, animals are able to conduct their daily activities optimally. Body and limb silhouettes can reflect the way of locomotion (e.g., dolphins have tapered bodies and fins adapted for swimming), hunting strategies (e.g., weasels have long slender bodies and short legs which allow them to catch mice into tunnels), or dwelling behaviours (e.g., moles have cylindrical bodies, shrink back limbs and digging forelimbs apt for burrowing). The size being equal, the weight of birds in comparison with mammals is lighter, thanks to lightweight skeletons, which allow birds to fly. Scales, plumage, or fur can cover epidermis. They have different textures and properties such as disguising colours, which match with the surrounding environment, or signalling tints, which convey information to conspecifics or other species.
Body size	
Body colour	
Body parts	
Physical environment	
Aquatic	Animals live in very different habitats. In general environments can be aquatic, aerial, terrestrial (underground or over ground), or a combination of them. In relation to the medium(s) in which each species lives, special and collective adaptations can pertain. For examples, whales and other cetaceans lives all their life cycles in water, while seals and other pinnipeds, procreate and nurse on earth (or ice), but forage in water; thus the latter have adaptations for both diving and swimming, and terrestrial behaviours. The same occur in birds like diving ducks, which are adapted both for fly and dive. In relation to these adaptations, the physical environment of wearers should be taken into account when designing a device
Aerial	
terrestrial	
Living conditions	
Free living in wild places	The categorization of animals in wildlife, pets, livestock, and laboratory animals implicitly describes their way of living. Wild fauna lives unrestrained in its natural habitat (with the exception of zoological parks dwellers); companion animals share homes and gardens of the family which they are members of, having often the possibility to move freely outdoor; farm animals lodge in stables, cattle shed, and pigsty, or graze inside fences; and test animals are housed in lab cages and facilities. Whether wearers live freely (e.g., wildlife), in semi-confinement (e.g., pets and grazers), or in captivity (e.g., laboratory and zoo animals), different technologies can be exploited in relation with how much the technology can be shifted from the wearer’s body to the surrounding environment. In general, more an animal lives near or inside human infrastructures, broader is the range of technologies available. For example, inside laboratories, cameras which record the behaviour of rats and mice is quite used; the same technologies is used with many challenges in wild animals
Free living in anthropogenic places	
Semi-confined	
confined	
Behaviours	
	Such as postures, cleaning, sociality, mating and reproduction, predation.  Further reflection is needed

Movements	
	Such as movements on earth, underground, in water and in the air.  Further reflection is needed
Psychology	
	Such as tolerance. This is related with abnormal behaviours such as stereotypes (psychological conditions observed in captive and laboratory animals: decreasing in feeding, atypical eliminating activities, isolation, stereotypes, desertion of brood, increasing of aggressiveness).

## List 2 of features of design



## Appendix 3 – Workshop slides and material

3/28/19

### Objective: designing a wearer-centred GPS prototype for cats

#### Participant skills

*Take 5 minutes to answer the questions below and 10 minutes to discuss your answers with your team*

- Have you ever used wearable computers (e.g. fitbit)? Briefly tell what and why  
.....
- What do you do for living? Briefly overview it  
.....
- Do you have any experience in crafting/DIY, soldering, prototyping? Which?  
.....
- What is your experience with animals?  
.....

### Warm-up: make a toy for a cat (Rough and Rapid) – 20 min

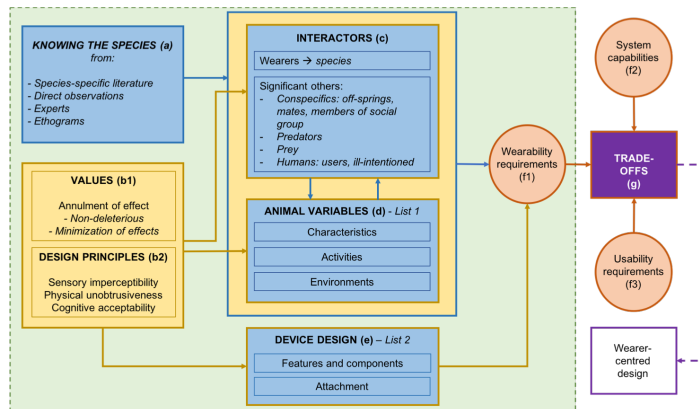
Step 1:  
Brainstorm ideas: 5 min  
*jot down or sketch ideas here*

Step 2:  
Make it: 10 min  
*quickly make a rough  
version of your idea with  
the material provided*

- Cardboard
- Scissors
- Pens and markers
- Ruler
- Modeling clay
- Twine
- Glue
- Sellotape
- Paper

Step 3  
Reflect: 5 min  
*Quickly show and share your idea to each other*

## 1. framework and overview of its elements



## Today we redesign for a Hodges



### Characteristics:

- black and white coat, medium-long hair.
- male neutered cat.
- 10 years old
- weighs around 8 kg.

### Environment:

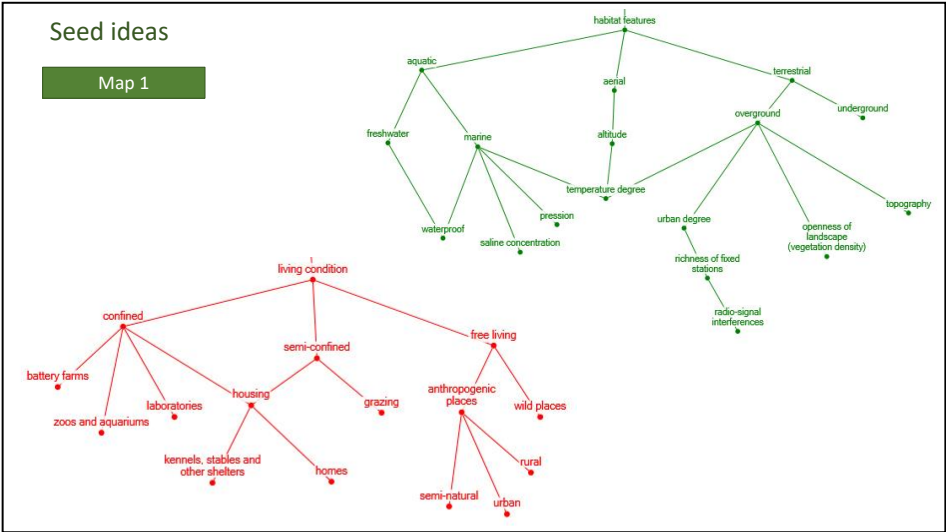
- lives in a colony with other 12 adult cats and from 4 to 5 kittens depending on the yearly litter, two humans and two dogs.
- house fully furnished. Tiled and wooden floor.
- access to a garden through a cat flap kept always open: Hodges is allowed to roam outside home as he wishes.
- garden has both concrete tiles and soil, plants and trees, a garden cat tree in which cats can jump, and a cabin in which the cats of the colony can rest.
- garden delimited by wooden fence and metal net.
- home in a countryside village near a wood.

Today we redesign for a Hodges

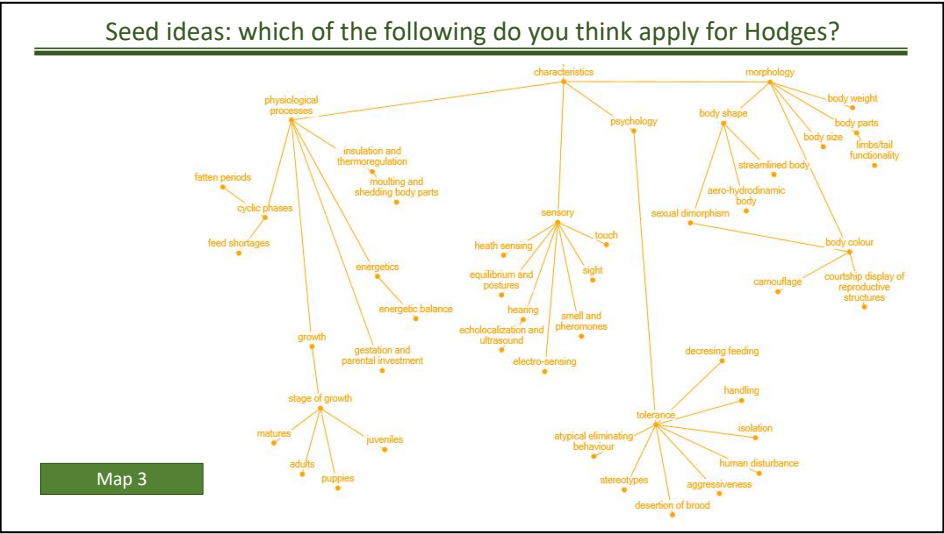
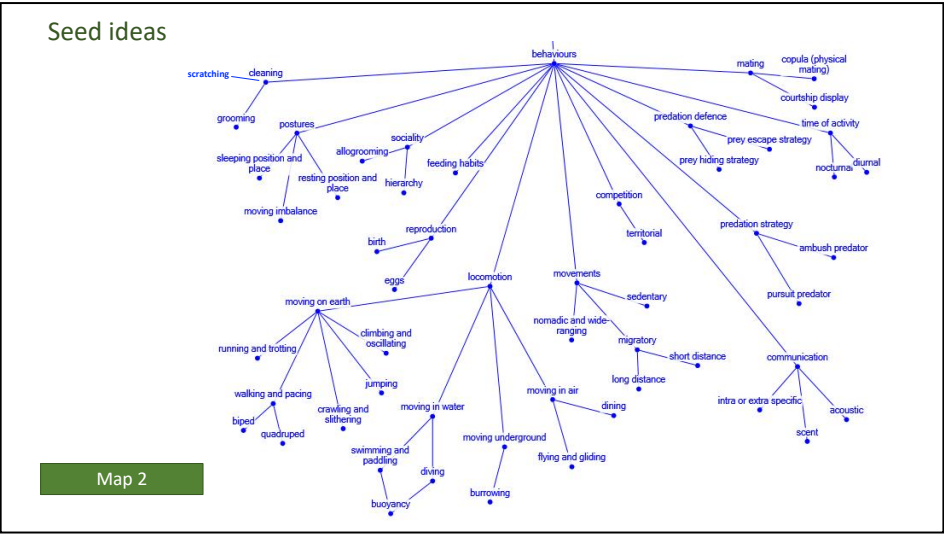


**Activities:**

- Hodges likes to spent time in the garden
- He often sleeps inside the cabin where he has a favourite spot
- He's a very curious individual: he approaches people to see what others are doing and he often rubs his head, neck, and body on objects and people. He plays a lot with sticks and objects he find on the floor.
- He grooms a lot his fur.







### Brainstorm tips and rules

- |   |   |
|---|---|
| 1- Space: wall space to hung ideas                        | 4- Question: "how might we improve wearability for cats?"<br>Hang it to the wall and read it loud |
| 2- Material: stack of post-its and a marker to write with |   |
| 3- Brainstorming rules:                                   | 5- start the clock: 10 minutes  |
| • Defer judgment  | • one idea per post-it  |
| • Encourage wild ideas                                    | • be visual   |
| • Build on the ideas of others                            | • Hang each idea underneath the written question as your teammate create them                     |
| • Stay focused on the topic                               |   |
| • Once conversation at a time                             |   |
| • Be visual   |   |
| • Go for quantity   |   |

### Pick features, environments and characteristics

30 min - *Select the features: take some time to select those features you think they might be on a cat-centred wearable.*

1- survey the features: *each teammate reads and presents the features he/she created in the brainstorm. Which wearability problem do your ideas solve?*

2- vote for the most solvable idea: *Think of which ideas you'd like to take forward. Decide in silence first, so you are not swayed by others. Draw an **O** in one corner of the idea that you feel solve the most a side effect.*

3- vote for the most implementable idea: *Draw a **X** in a corner of the idea that you feel is most possible to design.*

4- count the votes

5- discuss with the team if the vote is split

6- Pick the features to make a prototype (ideas with most votes get chosen)

## Seed ideas

5 min - write the seeds idea circled on post-its and order them

## characteristics

activities

environments

## Brainstorm

30 min - *Brainstorm about what do you think make a GPS device wearable for cats*

## How might we improve wearability for cats?

Choose device **features** like case, collar, material, colour, texture, size, protrusion, area of the device surfaces, and the **attachment**.

How would you redesign it to be more wearable, IOW less disruptive.

Use the framework (principles, variables, interactors, trade-offs)

Think about the physical and sensory characteristics, daily activities, and environments in which indoor&outdoor cats like Hodges live.

Think about when you meet a cat in a street or a path or in the countryside. What do they do? How do they interact? But also think about **why owners** put the device on them and what they need from it as users. Think about the **technological capabilities** as well

4. Make it

45 min - *Start building a wearable with Hodges! When first moving from an idea on paper to a physical prototype, it should be pretty rough and scrappy. Use the material provided to build an initial prototype.*

markers

clay

paper

scissors

Cardboard boxes

boxes

glue

Plastic boxes

string

tape